LAWRENCE J. LUKENS

Firing of Locomotives

By

J. W. HARDING

DIRECTOR, STEAM RAILROAD SCHOOL

AND

I.C.S. STAFF

HAND FIRING OF LOCOMOTIVES
OIL-BURNING LOCOMOTIVES
TYPE C-2 LOCOMOTIVE BOOSTER

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HAND FIRING OF LOCOMOTIVES

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TYPE C-2 LOCOMOTIVE BOOSTER

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Serial 1960 — Edition 1

FIRING COALS OF THE EASTERN STATES

INTRODUCTION

1. Purpose of the Instruction.—Before a man can be an efficient locomotive fireman, there are many things that he must learn. Some men acquire this knowledge during years of firing service, learning from the hard knocks of experience. Others learn through the quicker and easier method of studying the experience of others as set forth in written instructions. The purpose of this instruction is to furnish practical information to locomotive firemen on all necessary subjects pertaining to the firing of the coals of the Eastern States.

2. Importance of a Knowledge of Coal.—One of the first essentials of an efficient fireman is a knowledge of the different kinds of coal. There are more than fifty varieties of coal in the country and every variety is burned in locomotives. Some of these coals are good steam coals, others are only fairly good, and still others are burned in a locomotive firebox only with the greatest difficulty.

As there are so many grades and varieties of coals, it is easy to understand that the methods of firing employed must be suitable to the grade and variety of the coal used, and the fireman must know what method to employ in each case. Furthermore, the ash-pan, grates, firebox, and draft adjustment must be suitable to the coal being burned, and the fireman should know whether the conditions are right. If an engine is designed to

burn a certain type and grade of coal, better results will be obtained with that grade than with either a better or a poorer grade. For that reason, where conditions will permit, each coaling station should be continuously supplied with the same grade and type of coal, and the locomotives should be properly equipped and drafted to burn it. Under conditions where many grades of coal are supplied and must be burned in the same firebox, the fireman must learn to fire the different grades so as to obtain the best results with each.

COALS AND THEIR COMBUSTION

3. A study of the coals of the Eastern States shows that they consist of high-rank bituminous, semibituminous, semianthracite, and anthracite. Bituminous coal may be either a coking coal or a free-burning coal.

Coals that coke vary widely in coking properties. Those with the greatest tendency to coke swell up in burning, become pasty, and fuse into a mass of porous coke. This forms a protective covering over the surface of the fire, restricts the draft through the fire, and so cuts down the steaming capacity of the boiler. To offset this, the coke covering must be broken up from time to time with a slash bar, so that air can pass through the fire readily.

Coals that do not have a strong tendency to coke may become partly pasty but retain their form to a considerable extent unless disturbed. With some coals, if the rake is used on the fire, or, in some cases, if the grates are shaken roughly, the coal will run together and fuse into a porous coke that will cause considerable trouble.

Some coals have no tendency to coke. Such coals do not swell, soften, or fuse, but burn away gradually, becoming smaller and smaller until only the ash finally remains. Such coals are called free-burning to distinguish them from the coking coals. They may be raked freely without causing trouble unless in the process some of the ash is raised up into the hot zone of the fire, where it will melt and clinker.

4. Gas Coals.—In locomotive service, the bituminous coals are commonly known as gas coals, owing to the fact that about one-third of the weight of the coal is converted into gas during the process of burning. This gas is very hard to burn economically. If the firebox and draft appliances are not designed and adjusted to burn it, or if the firing is not done properly, a great waste of fuel will occur and clouds of black smoke may be produced. The other two-thirds of the coal consists of fixed carbon. This is the part that forms coke, which burns without smoke, like the coke of commerce. It burns at a bright red heat, without flame, and remains incandescent as long as burning continues, the heat produced by the combustion being sufficient to maintain incandescence. To obtain smokeless combustion, therefore, the gaseous part of the coal must be burned completely. It is comparatively easy to burn smokelessly any coal in which the gaseous matter does not exceed one-fifth of the weight of the coal.

5. Best Steam Coals.—Coals containing about one-fifth gaseous content and four-fifths fixed carbon give the best results for steam purposes. Those with a greater gas content have a lower heating value and give trouble from smoke, unless conditions for smokeless combustion are just right. Those with less than one-fifth gaseous content also have a smaller heating value, and are harder to ignite; but they burn without smoke even under rather unfavorable conditions.

6. Gases in the Coal.—The gases in the coal are driven off while the coal is being heated to red heat and are burned before the fixed carbon begins to burn, this action requiring from one-half minute to two minutes, depending on the rate of burning and the consequent firebox temperature. Where bituminous coal from the Eastern States is being burned, this means that one-third the weight of coal that is put in at a fire is burned within two minutes after firing. If a heavy fire of, say, nine scoops holding 15 pounds each were to be put in at a fire $(9 \times 15) \div 3 = 45$ pounds of gaseous matter would be burned within two minutes, which is $22\frac{1}{2}$ pounds per minute. As about 300 cubic feet of air is required to burn a pound of the

gas, $300 \times 22\frac{1}{2} = 6{,}750$ cubic feet of air, or the capacity of about three ordinary box cars, would have to pass through the firebox per minute merely to burn the gas of the nine scoops of coal. The coke of the coal burns in the fire bed with the air that comes through the fire, but the gas burns in the firebox space above the fire bed, and the air necessary to burn it must be supplied at that point. If the air is not supplied the gases cannot burn, but will simply be distilled from the coal by the heat of the fire and pass out of the stack unburned.

7. Coal Loss Through Unburned Gases.—When burning the high-volatile coals of the Eastern States, a very serious loss of fuel may occur through the escape of unburned gases unless the fireman knows how to prevent it. In burning, 1 pound of fixed carbon evolves 14,650 heat units, whereas 1 pound of the coal gases evolves 23,500 heat units. In a high-volatile, high-grade coal composed of two-thirds fixed carbon and one-third gaseous content, the two-thirds pound of fixed carbon would evolve 9,766 heat units and the one-third pound of gases would evolve 9,669 heat units. In other words, the one-third pound of the gases actually represents one-half of the heat value of the pound of coal. With such a coal, if a fireman allows his fire to get into a condition such that only half of the gases escape unburned, he would have the same waste of coal as if he burned all the gases but threw every fourth shovel of coal off the tender. With a high-volatile coal, it is an easy matter to waste a large quantity of fuel through unburned gases if there is insufficient draft or firebox volume, or if the fire is allowed to become dirty or too thick, or holes or banks are allowed to form. A much larger firebox volume is needed to burn a high-volatile coal without smoke than to burn a low-volatile or smokeless coal, and much more skilful manipulation of the fire is necessary.

8. Smoke-Forming Constituents of Coal.—In the manufacture of illuminating gas, a high-volatile coking coal is placed in an air-tight retort and heated until all the volatile is driven off. This process results in four products: coke, gas, tar, and sulphate of ammonia.

The coke is the fixed carbon and ash of the coal, which are left after the volatile is driven off through the heating of the coal. It amounts to from 65 to 75 per cent. of the weight of the coal, which is 1,300 to 1,500 pounds per ton of 2,000 pounds.

The gas obtained averages about 9,000 to 10,000 cubic feet per ton of coal coked.

The tar averages from 4 to 6.5 per cent., which is from 80 to 130 pounds per ton of coal.

From a ton of coal about 20 to 25 gallons of watery liquor is obtained, from which 1 to 1.5 per cent. (20 to 30 pounds) of sulphate of ammonia is obtained.

9. High-volatile coal in burning separates into four parts—coke, gas, tar, and ammonia liquor—the first three of which must be taken into account by the locomotive fireman. The fixed carbon, which may be coke, forms the fire bed, and there must always be a sufficient depth of it carried to prevent the draft from disrupting the fire bed and forming holes. Otherwise, the fixed carbon does not cause serious trouble, as it does not form smoke in burning, but lies quietly on the grates until it is completely consumed. If the fixed carbon cakes over the bed of the fire and forms a crust that prevents the free passage of air through the fire bed, it must be broken up periodically with the slash bar so as to allow a free passage for the air, otherwise it will be impossible to keep up the steam pressure. In breaking this crust, care must be taken not to raise the ash up into the hot zone of the fire, as it will fuse and form a clinker that will produce trouble. The fire bed must not be penetrated with the slash bar farther than is necessary to break the crust.

10. Quantity of Gas Given Off.—The quantity of gas given off by a coal may vary from 5,000 cubic feet per ton in a low-volatile coal to 10,000 cubic feet per ton in a high-volatile coal. If the firebox volume, the air passages through the ash-pan and the grates, and the amount of draft are sufficient, and the draft is properly adjusted for burning the proportion of gas produced by the coal, there should be no difficulty in burning the gaseous portion of the coal smokelessly, provided the fire-

box is equipped with a brick arch. If smoke occurs at heavy rates of firing, it may be reduced by leaving the fire-door on the latch for a short period after each fire, so as to admit above the fire the air necessary to burn the gases while they are driven off in heaviest volume.

11. Tar Distilled From the Coal.—The tar distilled from the coal consists of about 50 per cent. of pitch and 50 per cent. of hydrocarbon oils and liquid paraffins. A coal rich in tarry vapors is a most persistent smoke maker, as the tar constitutes the worst smoke-producing constituent of the coal. The power of tarry vapors to make a dense black smoke will be readily understood if a small piece of tar is thrown on a fire and the quantity and color of the vapor that arises from it are noted. If the firebox temperature is high enough, any tar that escapes burning is decomposed into soot and fixed gases. The soot makes dense clouds of smoke, while the gases that escape unburned are a source of fuel waste.

12. Tendency of Coal to Produce Smoke.—The tendency of a coal to produce smoke depends on both the relative total quantity of volatile matter and on the temperature at which the smoke-producing part of the volatile matter is driven off. For example, Illinois and West Virginia Pocahontas coal contain practically the same amount of smoke-producing volatile matter. The Illinois coal gives off the major portion of its smoke-producing volatile at a low temperature (between 900° F. and 1,100° F.), and for that reason is a very hard coal to burn without smoke; the Pocahontas coal gives off the major portion of its smoke-producing volatile between 1,200° F. and 1,500° F., a temperature at which it is burned smokelessly with but little effort. Connellsville, Pennsylvania, coal gives off its major portion of smoke-producing volatile between 1,100° F. and 1,500° F., but as it contains a much greater proportion of smoke-forming volatile it must be burned with great care to prevent dense black smoke.

13. Rate of Distillation of Volatile.—Experiments have shown that the quantity and quality of the volatile distilled from a coal depends on the rate at which the coal is heated and

the volatile driven off. With a slow rate of heating, the volatile is smaller in quantity and has a higher percentage of gas and a smaller amount of tarry matter. With a rapid rate of heating, a larger amount of volatile is obtained and a much larger proportion of this is in the form of tarry vapors and of hydrocarbon gases, which are hard to burn without smoke. For that reason, it is much harder to burn a coal without smoke at high rates of combustion than at low rates of combustion if the coal contains heavy smoke-producing volatile matter. Such a coal must have ample draft and ample air spaces in ash-pan and grates, the fire must be clean and as light as can be carried for the work the engine is doing, and there must be no leaks in the firebox or at the front end. At high rates of burning, smokeless combustion will be helped greatly by swinging the fire-door or leaving it on the latch for a short time after each fire. The fire-door must be swung shut after each scoop, so as to maintain a sufficiently high firebox temperature to insure smokeless combustion.

14. Smokeless Coals.—Coals, such as the semianthracite and semibituminous coals, that have not more than 20 per cent. of volatile matter are usually known as smokeless coals, because they can be burned at a much higher rate than the bituminous coals without producing black smoke. The reason for this is twofold: first, they have a smaller amount of volatile matter, and second, most of the tarry matter has been driven off through the longer period of pressure to which they were subjected. On the other hand, they are more friable and are not so well suited for transportation and repeated handling as the bituminous coals, especially the central bituminous coals of Illinois, etc., so they carry a higher percentage of slack coal, which must be taken care of by the fireman in order to avoid a large fuel loss.

15. Slack Coal.—Probably the worst fuel loss that a locomotive fireman has to contend with is that which occurs through the escape of unburned fine coal. Where the percentage of fine slack coal is very high, this loss may amount to one-quarter or even one-third of the coal fired. As a scoop of

coal is being fired, the draft picks up the fine coal and shoots it through the tubes and out of the stack, in many cases even before it has been heated sufficiently to drive off the volatile gases. The harder the engine is working the stronger will be the exhaust and draft and the greater will be the fine-coal loss. That is one reason why the fuel record of a man in heavy freight service suffers when compared with the record of a man in light freight service of moderate schedule speed. Not only is the fine coal wasted, but the sparks and live cinders thrown out along the right of way are responsible for many fires during dry seasons of the year.

16. Reducing Slack-Coal Loss.—The best method of reducing the loss through unburned fine coal is to wet the coal until the fine particles stick together while being fired. This can be done only by thoroughly drenching the coal at least a half hour before leaving time, so that the surplus water will have time to drain off. A *light* wetting will not prevent the loss of the fine coal and will add to the fuel loss, because the water must be evaporated and heated to the stack temperature at the expense of the heat of the firebox. In case the coal is sprinkled to keep down the dust in the cab, only just enough water to serve the purpose should be used, to reduce the loss through evaporation of the water.

17. Ash From Coal.—The analyses of coals of the Eastern States show that the ash may vary from 2 to 15 per cent. of the weight of coal. A fireman firing a coal with 15 per cent. of ash would fire 300 pounds of ash and 1,700 pounds of coal for each ton of coal used; with a coal having only 2 per cent. of ash he would fire only 40 pounds of ash and 1,960 pounds of coal. Furthermore, the extra 260 pounds of ash in the high-ash coal would clog the fire and probably clinker, and would interfere greatly with the proper burning of the coal. It certainly would cut down both the efficiency and the capacity of the firebox, and would tend greatly to produce smoke.

18. Foreign Impurities.—From the fireman's viewpoint the ash of a coal includes not only the inherent ash which is a definite part of the composition of the coal but also the

impurities that become mixed with the coal during the process of mining and in transportation and after handling. The impurities foreign to the coal are the real trouble-makers. The inherent ash of a coal will not cause trouble from clinker if the fire is properly manipulated and the ash is not raised up into the hot zone of the fire. The foreign impurities, on the other hand, are sure to cause trouble.

The foreign impurities may consist of: iron pyrite, which occurs in some beds of coal in balls, bands, and lenses and in other beds in veinlets or as small particles and usually is a trouble-maker on account of the tendency of its iron to form clinker; slate, shale, and sandstone from the roof of the mine; slate, shale, and sulphur balls sandwiched in between the coal strata; clay from the floor of the mine; and pieces of iron, rock, and earth that are picked up en route or in the subsequent handling of the coal.

19. The foreign impurities are very apt to give trouble through clinkering. If they do not fuse they settle down onto the grate and as the run proceeds gradually form a screen on top of the grate that shuts off a large part of the grate air space and so restricts combustion. If the fireman does not know the cause of the trouble he will probably fire more heavily than usual, with the result that the thickness of the fire bed will be increased and the steam production decreased.

A great deal of worry and hard labor will be avoided if the fireman will watch every shovel of coal fired for pieces of rock, slate, and other impurities. These should be picked out of the coal and placed in a pile at one side near the gangway where they can be thrown off at some point where there is no danger of hurting persons who might possibly be along the right of way.

20. Hard Clinker.—The formation of hard clinker in a locomotive firebox is one of the chief causes of a fireman's troubles. Where clinker does not form, it is a comparatively easy matter to carry a light, level, clean fire that is easy on the coal pile and makes steam freely. When clinkers form, the fire becomes dirty, grows thick, burns unevenly, smokes, and steam

pressure is maintained with the greatest of difficulty. Since the hard clinker, which is the form ordinarily met with, is formed generally by the melting of some foreign impurity in the coal, the way to avoid the clinker is to watch the coal for impurities and pick them out before firing the coal. The work required to do this is as nothing compared to the work and worry caused by throwing the impurities on the fire with the coal.

Hard clinker is sometimes formed by inserting the slash bar too deeply in the fire and raising some of the ash into the hot zone of the fire, where it melts and in cooling cements a lot of coal and ash together into a big clinker. The way to avoid this is to use the slash bar as little as possible, and then with care.

The appearance of the fire indicates when a clinker is forming. When a spot in the fire begins to grow darker in color than the rest of the fire and it is not due to a bank, it indicates that the air is restricted through that spot, probably due to the formation of a clinker. As soon as this is noticed the clinker should be broken up by a careful operation of the grates. The time to do this is when the clinker first forms. If it cannot be broken up by shaking the grates, it should be raised to the surface of the fire and removed at the first opportunity.

21. Soft Clinker.—Soft clinker is a slag formed by the chemical combination of the constituents of the ash at firebox temperature. To bring about this chemical combination, sufficient heat must be supplied to cause fusion. When a soft clinker first forms the appearance of the fire is the same as if a hard clinker had formed, but the soft clinker grows steadily in size until finally it spreads over the whole grate area. Inspection will show that the clinker is in a fluid condition underneath the crust. The fluid portion penetrates through the lower ash and often hangs like icicles from the grate bars.

Fortunately all ash does not contain the right constituents for combining chemically to form a slag at firebox temperatures. Also, the temperature of fusion usually is higher than the temperature to which the ash is subjected. It should always be borne in mind, however, that the temperature may be near slagging temperature and anything that may increase it only

slightly may cause the ash to start slagging, and once this is started, it is practically impossible to stop it. The only way to remedy the trouble is to pull the fire, clean the firebox *and the grate,* and start a new fire.

22. Anything that increases the ash-pan temperature has a tendency to cause the formation of soft clinker, and anything that tends to reduce that temperature tends to prevent the formation of clinker. Therefore, as a precautionary measure against the formation of clinker, the ash-pan, which should have ample air openings, should be kept clean and after the grates are shaken, when weather conditions will permit, the hot ashes should be cooled by spray piped from the injector overflow pipes. The grates should not be shaken hard enough to shake burning coal into the ash-pan.

23. Mixing Coals.—Many coals may be mixed and burned without causing trouble from clinker. On the other hand, two coals, neither of which clinkers in burning, may cause considerable trouble from clinker if mixed and burned together, or if burned in the wrong order. For example, if anthracite or semianthracite is fired on a fire bed of bituminous coal, the result is almost sure to be disastrous, whereas bituminous coal can be fired on a fire bed of anthracite without the least trouble. It is well, therefore, for a fireman to know whether the coals at the two ends of a division can be burned together without causing trouble.

CONDITIONS FOR ECONOMICAL COMBUSTION

24. Draft of Locomotives.—It is important that an engine have the proper draft for burning coal economically at the rate necessary to supply the maximum amount of steam. If the draft is not sufficient, the engine will not steam, especially when working hard. If the draft is not distributed evenly, the fire will not burn evenly. When the action of the draft on the fire is not what it should be, the fireman should report it, being careful to tell exactly what is wrong. It should be borne in mind that while the action of the draft on the

fire is not right, the trouble may not be due to wrong adjustment of the draft appliances, so no readjustment should be made until the actual cause of the trouble is located. If the fire indicates too little draft the draft appliances may be properly adjusted to produce the necessary draft, but steam or air leaks into the front end, or an obstruction in the ash-pan, grates, tubes, front end, or the netting may be reducing the amount of air flowing through the fire. Of course, the draft can be increased by reducing the size of the nozzle or by bridging the nozzle, but that will simply increase the waste of fuel through increasing the back pressure in the cylinders. The proper procedure is to find the cause and remedy that without touching the draft appliances unless they are found to be at fault. The ash-pan openings may be partly closed or the pan may be too full of ashes. A large number of air openings in the grate may be filled up. Often 60 per cent. of the openings have been found entirely closed. A large number of the tubes may be plugged up or the netting may be choked. The fireman should determine wherein the trouble lies so that he can turn in a correct report.

25. Draft Restrictions.—If a number of the air spaces in the grate are stopped up the fire will burn both poorly and unevenly on account of a lack of air. If the ash-pan opening on one side becomes partly closed up and the total amount of ash-pan air opening is small, the fire will burn poorly on the side on which the ash-pan opening is partly closed.

A fireman should insist that the real cause of any trouble be located *before any change is made in the draft appliances.* Of course, the draft can be regulated to offset the effect of leaks or other defects, but this means burning more coal to keep up the steam supply and additional work for the fireman. On the other hand, if the real cause of the trouble is located and remedied, the extra coal and work can be saved.

26. Failure of Engine to Steam.—Failure of an engine to steam, after being fired in accordance with the best practice, can generally be laid to a condition or set of conditions that decrease the draft or flow of air through the fire.

This may be due to conditions over which the fireman may or may not have control. The dampers or ash-pan netting may not be open, or the ash-pan may be full of ashes. Conditions over which he has no control are leaky steam pipes or superheater units, wash-out plug leaking in front end, blocked flues or netting, air leaks into smokebox, exhaust nozzle loose and leaking, and exhaust-nozzle tip of the wrong size or out of line with the stack. There may not be sufficient opening through the grates, or bricks may have fallen out of the brick arch.

The symptom of a reduced draft through the fire is difficulty experienced in getting the fire to burn white, as it will have a more or less dull color. Leaking tubes apparently reduce the draft out of all proportion to the extent of the leak. This is due to the fact that when water is heated to form steam, it increases in volume about eighteen hundred times. The steam generated from a small leak in the tube-sheet then has an appreciable effect in decreasing the draft through the fire.

27. Scale and Soot.—The effect of scale and soot on the steaming qualities of an engine is very marked. The loss in heat transmission due to ordinary scale varying in thickness up to $\frac{1}{8}$ inch may amount to 10 or 12 per cent. This means that out of every ton of coal fired from 200 to 250 pounds is practically wasted. In other words, in doing work that ordinarily would require the fireman to fire nine tons of coal with tubes clean of scale, the scale would make him fire ten tons, and he would have a much harder struggle to maintain steam pressure. On some roads today it is the practice when a locomotive has been out of the shop for six or eight months to either reduce the nozzle tip or to bridge it in order to offset the bad effects of scale and leaks. A much better practice is to treat the water and so avoid the formation of scale.

Soot is formed whenever coal is burned, but the better the combustion, the less soot will be formed. When the condition of the fire or careless firing causes smoke, clouds of soot are formed that coats the heating surfaces and seriously retards the transfer of heat to the water. Soot is said to be five times as good a non-conductor of heat as asbestos. Of course, the

scouring action of slack coal passing through the tubes tends in a measure to clean them of soot, but even at the best there is a considerable fuel loss through soot. The fireman should watch for soot and should see that the tubes are bored out and cleaned frequently, thereby saving himself much unnecessary labor.

28. Waste at Pop Valve.—With a free-steaming engine, it is often difficult to prevent a large waste of steam at the pop valve. For every minute that the pop is blowing, 30 pounds of coal is wasted. If a scoop of coal is assumed to weigh 15 pounds then two scoops of coal are wasted for each minute the pop is open. If during a run the aggregate time of blowing equals 30 minutes the coal wasted will amount to $30 \times 30 = 900$ pounds. With the two pops blowing occasionally, which sometimes happens, the quantity of coal wasted will be increased. Much labor and expense can then be saved by using care to prevent the pop from blowing.

If the fireman knows the run, it should be a comparatively easy thing for him to plan each fire far enough ahead so that when a regular stop occurs the pop can readily be prevented from opening. In local passenger service, when stops are many and short and stations close together, there is added difficulty in preventing pop waste. Just before closing the throttle the engineer should put on the injector and the fireman should crack the blower. This should prevent the pop from opening; but if indications are that it will not, the fire-door should be put on the latch or swung open and shut just enough times to prevent the pop from opening. While the engine is using steam, the fire-door should never be left wide open to prevent the pop from blowing or to cause the pop to cease blowing, as the large volume of cold air that would flow in a continuous stream through the firebox and tubes would cause tube leakage.

29. Cooperation of Engineer and Fireman.—The engineer and fireman must work in harmony with each other if good results are to be obtained. When pulling out of stations, the injector should not be started until the fireman has the fire in good condition, and the steam pressure is increasing. Otherwise the fire will have to be crowded to hold up the steam pres-

sure. When approaching shutting-off points, the fire can be allowed to burn down somewhat, and the water level at this time should not be so high as to prevent the injector from being used to keep the engine from popping. The engine should not be run first with a light throttle and then with a heavy throttle, nor should the cut-off be changed frequently, as working the throttle and reverse lever in this way makes it impossible for a fireman to carry a steady fire and an even steam pressure. The position of the throttle and lever should, as far as possible, be changed only when a change in grade makes it necessary.

DETAILS OF FIRING

30. Preparing Fire for Start.—It is of the greatest importance to have a good fire with which to start the trip. If the fire is not put in shape before starting, it will give the fireman all kinds of trouble. For that reason he should get around in sufficient time to have his fire in perfect shape before leaving time, as he thereby will save himself much worry and hard labor during the run.

On arriving at his engine he should see whether the fire has been well cleaned. If it has not, he should knock out any clinker or ash that remains. Next, he should close the fire-door and put on the blower long enough to start the fire burning brightly so that he can detect any dead spots in it. Sometimes the fire cleaners in spreading the live coals after cleaning the fire do not entirely cover the grates and fire green coal on the bare spots. With a coal that ignites freely this will not matter so much, as the green coal will gradually ignite and the fire will spread over the dead spot. However, if there is a dead spot with the low-volatile, harder-to-ignite coals like the semi-anthracite, it will cause so much trouble that it should be done away with before starting. The green coal should be pulled away from the dead spot, the grate covered with good live coals, the green coal spread over the live coals, and the blower applied just long enough to ignite the green coal thoroughly.

31. Building Up the Fire.—After the fire has been put in good condition all over the grate surface, fresh coal should

be lightly spread over it, and, if necessary, the blower put on very lightly. If there is sufficient time in which to build up the fire without the blower, it should not be used. It has been found by experience that when the blower is used freely in building up a fire, more clinker is formed and the fire is not in as good condition as when it is built up under natural draft. After the fresh coal that was spread over the fire is at a cherry-red heat, begin to build up the fire by spreading fresh coal thinly, first over one half of the firebox, lengthwise, and then over the other half. The idea is to always have one half of the fire at a red heat or better, when fresh coal is put on the other half, so that sufficient heat will be assured to burn the gases as they are driven off from the fresh coal. This method of firing will very materially reduce the amount of smoke produced in building up the fire.

32. The fire should be built up to the required thickness for the service as gradually as time will permit. Each fire should consist of only one, two, or three shovelfuls at a time, each being spread lightly and evenly over half of the firebox surface. A charge of coal that has been put on the fire must not be covered with more fresh coal before it has attained a red heat. Below a fairly bright red heat the first charge has not had its volatile matter driven off, and the second fire will simply retard the distillation and will cause the fire to build up too rapidly with green coal. Then, when the fixed carbon of the coal begins to burn, the hot zone of the fire will be so thick and so hot that clinker will result.

33. It is of the greatest importance to have a good fire covering the entire grate surface before leaving time for the trip. The depth of the fire will depend on the size of the coal, the weight of the train, and whether the start will be on an up grade, a level, or a curve. In other words, if the engine will have to work hard to start the train the depth of the fire at starting time must be greater than if the train is easily started. The coal necessary to keep up the steam pressure and to keep the fire in shape while the train is being started should be thoroughly ignited, and burning brightly before starting.

34. Depth of Fire.—It is important to know the best depth of fire to carry under various conditions. Many firemen do not understand this, and are in the habit of carrying one depth of fire at all times unless the thickness of the fire builds up during the run. This is a mistake that causes the fireman much extra work and worry, besides lowering his standing in the fuel records. For light loads, a light fire should be carried, while a thicker fire should be carried for heavier loads. It should not be thicker, however, than is necessary to withstand

TABLE I

EFFICIENCY OF BOILER AND FIREBOX

Depth of Fire Inches	Amount of Load Carried			
	Half Load Per Cent. Efficiency	Three-Quarters Load Per Cent. Efficiency	Full Load Per Cent. Efficiency	One-Quarter Overload Per Cent. Efficiency
6	73.5	67.5	64.0	60.5
7	68.5	67.0	68.5	62.0
8	65.0	64.0	68.0	63.0
9	63.0	60.5	66.5	62.0
10	62.0	57.0	63.0	58.0

the effects of the exhaust, as that thickness will give the greatest fuel efficiency and the least trouble in burning.

35. Fuel Loss Through Thick Fires.—The effect of the thickness of the fire on the efficiency of a certain boiler and firebox is shown in Table I. These results hold good only for the boiler from which the results were obtained. If a test for another locomotive were to be made, the best depths of fire would very probably be different from those given, *but whatever they were found to be, they would vary in a manner similar to these figures.* The results found in the tests are presented merely to emphasize the fact that a lighter fire will give better results at light loads, whereas a heavier fire must be carried for heavy loads.

From the table it will be seen that in this test a 6-inch fire gave the best results for half and three-quarter loads, but that the efficiency was greatest at half load and dropped away rapidly as the load was increased. The 7-inch fire was not as efficient as the 6-inch fire for half load, but gave best results from three-quarters to full load. The 8-inch fire gave best results between full load and one and one-quarter load. The 9-inch fire did not give as good results as the 8-inch fire, while the 10-inch fire was considerably less efficient.

36. Suppose that the man firing for the test had the habit of always carrying a 10-inch fire. How much extra coal would he have had to fire on that account? For half load he would be wasting 11.5 per cent., or 230 pounds, out of every ton fired. For three-quarters load, he would waste 10.5 per cent., or 210 pounds per ton. At full load he would waste 5.5 per cent., or 110 pounds per ton. At one-quarter overload he would waste 5 per cent., or 100 pounds per ton fired. Burning this extra coal means more work in feeding the fire, and more work in keeping the fire at its best, because the more coal that is burned the more dirty the fire becomes. This extra labor and trouble can be avoided by carrying a depth of fire best suited to the load.

37. Preparation of Coal.—Most of the coal furnished for locomotive service is run of mine. Due to differences in the nature of the coal, in mining methods, methods of preparation, etc., there is a big difference in the make-up of the run of mine from different mines. Run of mine from a district where the coal is soft and friable has a high percentage of slack and a correspondingly low percentage of lump coal. Furthermore, the lumps crumble when exposed to the high temperature of the firebox, so they need not be broken so small as the lumps of the harder varieties. With a soft, friable coal, therefore, the loss of unburned slack must be prevented by thoroughly drenching the coal.

38. Most of the coal from the Eastern States is of the harder varieties, so that it has a lower percentage of slack and a higher percentage of lumps, many of which are too large to

go through the fire-door. Now, fine coal and large lumps cannot be burned together, because the lumps burn slowly and tend to cause banks and clinkers; also, holes form around the lumps. A fireman will save worry and labor by breaking up large lumps to the size of medium-sized apples before shoveling them into the firebox.

39. Method of Firing.—The method of firing best adapted to the economical and smokeless burning of the bituminous coals of the Eastern States is indicated in Fig. **1**. This shows that the fire is carried level throughout the grate, except

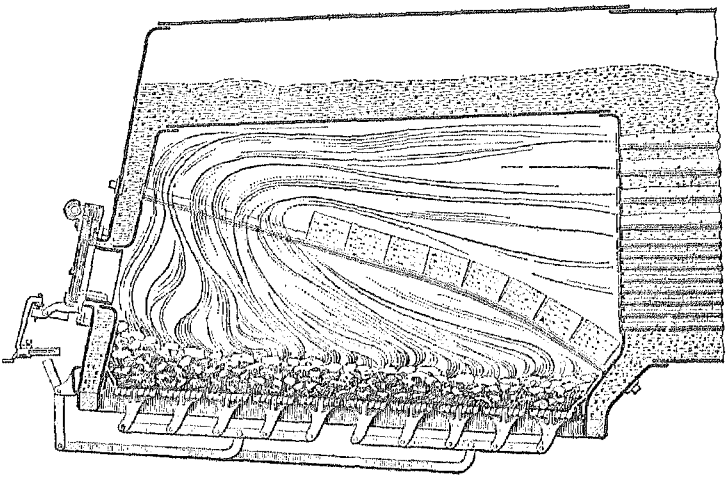

FIG. 1

near the firebox sheets, where a heavier fire is carried to prevent cold air from coming through at those points and causing the sheets to crack and the tubes to leak.

40. The thickness of fire carried should be as light as conditions will permit. A good portion of the fire should be at a white heat, the fire should be free from holes and banks, and the flame should be clear and non-smoky and short enough so as not to reach the tubes.

The thickness of the fire will increase if the ash continues to accumulate on the grate or if coal is fired faster than it is being

burned. The fire should not be allowed to become thicker through the accumulation of ash, because that will surely lead to the troubles that go with a dirty fire. If the grate does not clear itself, it should be shaken very carefully as often as is necessary to prevent an accumulation of ash.

The coal put in at one fire should always be allowed to burn down before another fire is put in that part of the firebox. This is a cardinal principle of firing. If this is done, the fire will not build up in thickness. When the fire is to be built up in anticipation of heavy work, such as climbing a heavy grade, the coal is fired faster than it burns, by shortening the intervals between fires. However, the intervals should not be so short that the coal of one fire does not have time to come to a bright-red heat before it is covered with the next charge of coal.

41. Firebox Temperature.—From the standpoint of both firebox efficiency and smokeless combustion, the temperature of the firebox must be kept high and as nearly constant as possible. If the entire surface of the firebox is covered with green coal at a fire, allowed to burn down and then covered with green coal, the firebox temperature will vary greatly and the steam pressure will vary correspondingly. Such variations mean smoke, leaky tubes, and waste of fuel. The best plan, where the firebox is not too large, is to fire the lengthwise halves of the firebox alternately. In this way, half of the fire can be at a bright-red heat all the time, which will maintain the high constant temperature necessary for good combustion. When the firebox is too large for firing halves, divide it into quarters and fire alternate quarters.

42. Placing the Coal on the Fire.—It is important that the fireman know where and how to place coal on the fire. With engines having sloping fireboxes, care must be taken not to put too much coal under the arch. Both the slope of the firebox and the force of the draft tend to pull the coal ahead, and unless care is taken the fire will be banked up next to the tube-sheet, causing the forward section of the grates to become clinkered over and stuck. Most of the coal should be fired at the back end of the firebox and in the corners and along the

sides. Fire only enough in the front end and in the middle of the firebox to prevent holes from forming.

The coal should be fired with only two or three scoops to the fire. It should be placed on the bright spots and never on the dark spots, as that has a tendency to form banks. The bright spots indicate the places where the fire has most nearly burned through. The intervals between fires should be lengthened or shortened according to the requirements. This procedure will make the fireman's work much lighter, as he will handle less coal and a steady steam pressure will be easily maintained. Also, the coal will be burned with much less smoke than it otherwise would be, as less gas will be liberated to a fire and more time will be allowed for the gas to burn before a new fire is put in.

43. The rate of firing will be in direct proportion to the draft, because the rate at which the fire burns depends on the rate at which the air is passing through the fire bed. Increasing the amount of air passing through the fire makes the coal burn faster; decreasing the amount slows down the rate of combustion. The amount of coal burning at any time must be sufficient to supply the steam necessary to operate the engine properly under the conditions prevailing.

44. Swinging the Fire-Door.—If the engine is not equipped with an automatic fire-door, the fireman should swing the door shut after every shovel of coal, which should be fired in a leisurely manner, so that the door will remain shut for a few seconds after each charge. This method requires a little work but saves the fireman a great deal of labor in the end. For, if he leaves the fire-door open, the cooling effect produced wastes much coal and so increases the amount that must be supplied by the fireman. Furthermore, if this extra coal did not have to be burned, a much cleaner fire would result.

45. Starting the Train.—By leaving time at the terminal station, there should be a good fire burning brightly all over the grates and of a suitable thickness for the work the engine will have to do in starting the train. Under some con-

ditions it may be an advantage to put on the blower for a time just before starting, so as to have a good hot fire. If the train is a heavy one, the new fire may be torn up by the heavy exhausts; so the fire-door should be placed on the latch to reduce the draft above the fire and lessen the tearing effect. When the reverse lever is notched back, a fire should be put in to repair any damage done in starting, and the fire after that should be maintained to suit the work of the engine.

46. When to Put in a Fire.—The student fireman generally experiences difficulty in reading his fire—that is, he is not sure just when a new fire should be put in—the result being that he generally errs on the side of too much coal and crowds his fire, or adds fresh coal before the coal already in the firebox has been sufficiently burned. When this is done, the fire becomes too thick, the passage of air through it is obstructed, the steam pressure falls and there is, depending on the coal used, a tendency for clinkers to form. The time elapsing between firings will depend on the coal, draft, cut-off at which engine is working, etc., and can be determined either by the appearance of the fire or by the time interval between fires. The experienced fireman does not generally regulate his firing so much by the appearance of the fire as by the intervals of time his experience has taught him must elapse between fires under various conditions. In other words, he expects his fire to be in the proper condition for a fresh supply of coal after a certain time. The judgment necessary for a fireman to determine correctly the time between fires can only be acquired by experience, and in the meantime he must be guided to a great extent by the appearance of his fire. When the coal he has fired before his last fire has burned down to a dazzling white heat, this section of the grates is ready for another charge of coal. For example, if his last fire consisted of three scoops of coal on the right side of the firebox, when the left side has burned to a white heat, his next fire should be along that side. When putting in a fire the fireman should practice making a quick survey of the whole firebox and thus ascertain the kind of fire that is being carried.

47. Heavy Firing.—Heavy firing with bituminous coal makes both labor and trouble for the fireman. Some firemen habitually fire from eight to fifteen scoops to a fire when the engine is working hard. That is just the time the most skilful firing should be done; yet by heavy firing the fireman not only wastes a great deal of coal but also reduces his chances of maintaining the necessary steam pressure. A heavy charge lowers the firebox temperature and allows the gases to escape unburned. Cooling the firebox reduces the rate at which steam is generated, thereby reducing the maximum hauling capacity of the engine. On a long grade with a heavy freight, this might mean doubling the hill, whereas a properly fired locomotive would make the grade without doubling.

If a coal composed of one-third volatile matter were to be fired in charges of fifteen scoops, each holding 15 pounds of coal, each scoop would have 5 pounds of gas. The 15 scoops would contain $5 \times 15 = 75$ pounds of gas, and $75 \times 300 = 22{,}500$ cubic feet of air, or the contents of ten box cars, would be required to burn the gases without counting the air necessary for the burning of the fixed carbon. The draft appliances are not adjusted to admit such a supply of air, and so most of the gases escape unburned. The consequence is that the fireman gets no useful results from half the coal he is firing, and just at a time when he should be getting all the heat that the coal is capable of giving. Firing two or three scoops to a fire at frequent intervals would cut his labor in half, maintain a better steam pressure, and greatly reduce the trouble from dirty fires. Furthermore, it would prevent the big fluctuations of temperature that occur with heavy firing, thereby preventing trouble from tube leakage.

48. Firing Poor-Steaming Engines.—Under favorable conditions—that is, when the coal is of fair average quality and the engine is properly drafted—it is a comparatively easy matter to carry a good head of steam if the fireman keeps in mind the correct principles of firing. However, when the conditions are not favorable, due either to the fuel or to the engine, it is only by exercising good judgment that it is possible

to have a successful trip. The fireman should not assume that conditions unfavorable to the free steaming of an engine should cause him to deviate from principles that his experience has taught him produce the best results, as it is only by the application of these principles that the greatest degree of heat can be obtained under any conditions, favorable or otherwise. He should, on the contrary, apply the principles of correct firing to the conditions under which he is working, and, even if the engine is not kept hot, be satisfied that the results derived from their application will be the best obtainable. For example, if steam leaks reduce the vacuum in the smokebox and therefore decrease the draft through the fire, special effort should be made to keep the fire clean and light, so as to facilitate as far as possible the passage of the reduced volume of air entering through the grates to the fire, and thus compensate for the reduction in the draft due to leaks. Care should also be taken under these conditions to fire more lightly than usual, as it is very easy to overcrowd the fire under any conditions that cut down the draft. The tendency, however, when an engine is not steaming freely, is to fire too much coal, which in a great number of cases merely aggravates the trouble. In the case of poor-steaming engines there should be closer cooperation between the engineer and fireman than is usually necessary when conditions are more favorable.

49. Filling Up of Firebox.—Trouble is sometimes experienced by the fire increasing in thickness rapidly even when the grates are shaken frequently. As it is practically impossible in certain classes of service to keep shaking the grates continually, steam failure and detention of the train result. There are two principal causes of filling up the firebox: an excess of ash or foreign matter in the coal, and incomplete burning of the coke. In the first case nothing can be done except to keep the fire as thin as possible by frequent shaking of the grates; but in the latter case the trouble can be avoided by changing the manner in which the coal is being fired.

Some classes of coal burn more slowly than others, and require more time for the gases to distill out, and less smoke is

emitted at the stack. Fresh coal is frequently added before the coal already in the firebox has completely burned, causing the fire to become too heavy. Coal of this nature should be fired as light as possible, erring, if necessary, on the side of too little coal rather than too much, until the correct method of firing is found. An examination of the contents of the ash-pan will show whether the trouble is due to impurities in the coal or too heavy firing, as in the latter case a large amount of unburned coke will be found in the ashes.

50. Shaking the Grates.—How frequently the grates should be shaken depends on the style of grate, the amount of ash in the coal, and the amount of clinker-forming material in the ash. If the grate has the proper air openings for the coal being burned, and the air openings are not plugged up, and if the ash from the coal is fine and does not clinker, it is possible to go from terminal to terminal without shaking the grates. On the other hand, if the air openings are not right, or are filled up, or if the coal is high in ash and clinkers and contains rock and slate that are not picked out before firing, it will be impossible to get along without shaking the grates. The fireman, therefore, must judge as to whether or not it is necessary to shake the grate; however, he should bear in mind that it should never be shaken except when necessary, as fire trouble is apt to result.

If the appearance of the fire indicates that there is a restriction of the air passing through, the grates should be carefully shaken and the shaking should be repeated every time the appearance of the fire indicates the necessity. The time to shake the grates is when the throttle is closed or when the exhaust is very light. The object of shaking is to remove the dead ashes and clinker from the bottom of the fire, and the shaking should stop at the first indication of live fire dropping into the ash-pan, not only to save fuel but to prevent burning out the grates by live fire in the pan.

Care must be taken always to lock the grates in their level position; otherwise, the fingers on one side of the grate bars will project up into the fire and will probably be burned off,

or clinker may get wedged between the fingers of adjacent grate bars and hold them open so that live fire can fall into the ash-pan.

51. Use and Abuse of Blower.—When the blower must be used, turn it on just as lightly as will do the work. If the blower is used too strongly and at the wrong time it will cause damage to the boiler. The most frequent abuse of the blower and the one that does the most damage to the boiler is using it too strongly with the fire-door wide open or when raking or cleaning the fire. In doing this work, the blower

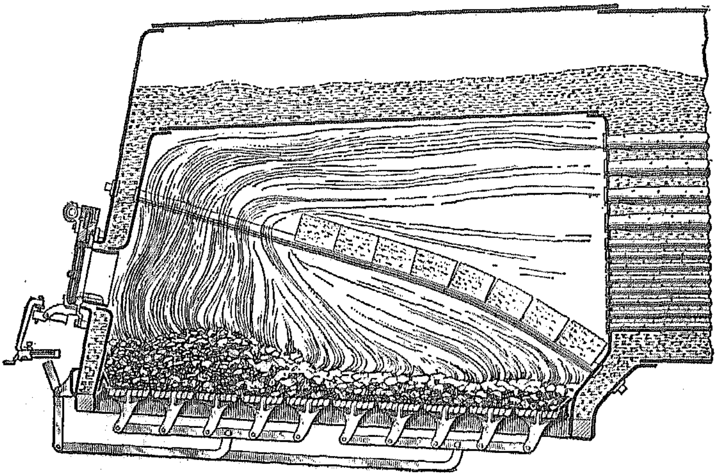

FIG. 2

should be put on only just strong enough to prevent the gases from coming out the fire-door into the fireman's face. Turning the blower on harder than is necessary is pretty sure to cause leaky tubes.

52. Banks in the Fire.—The condition of the fire known as a bank is indicated in Fig. 2, and is brought about by the building up of the fire bed considerably above the level of the fire at one point, due to slow burning at that point. Anything that restricts the draft through the fire at any point in the firebox will cause the thickness of the fire at that point to build up and a bank to form. A clinker on the grates, or firing

one scoop of coal upon another before the coal from the first scoop has had time to get red hot will form a bank. If the draft at one point in the firebox is very light and coal is fired at that point at the same rate as for the rest of the fire where the draft is normal, a bank will build up at the point of weak draft. A bank cuts down the amount of active grate area and makes the distribution of the draft uneven; therefore, it should be removed, if possible, or else coal should be fired around it so as to cause it to burn out. If it is not gotten rid of, it will start a bad clinker.

53. Holes in Fire.—When a hole is allowed to form in a fire, as in Fig. 3, it should be repaired at once. Never fill up a

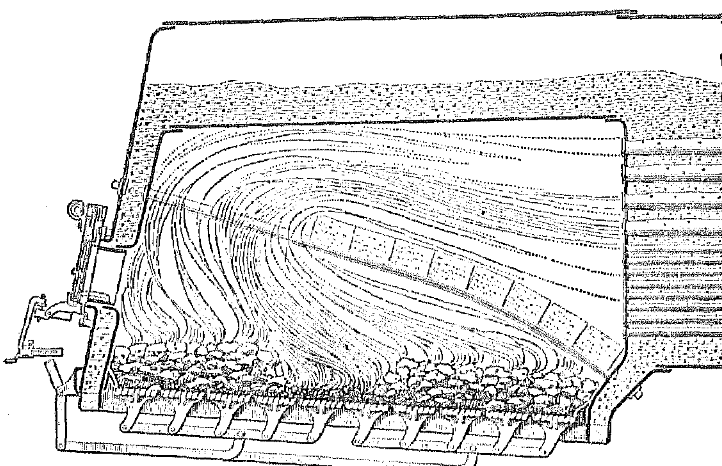

FIG. 3

hole with green coal, as it will either remain a dead spot or develop a clinker, depending on the kind of coal being burned. Fill the hole with live coals by leveling the fire at that point, and then sprinkle fresh coal over the part leveled.

When a hole develops, a large volume of cold air enters the firebox and passes to the tubes in a solid stream that cools the firebox and contracts the tubes and sheets, causing leaks. Also, so much air passes through the hole that the draft through the fire bed is greatly reduced. This still further lowers the rate

of combustion and the firebox temperature, and results finally in cracked sheets and leaky tubes.

54. **Clinkers in Fire.**—Clinkers cause the worst troubles for the fireman; therefore, he should take all precautions to avoid them. In case they form, the first opportunity must be taken to get rid of them, which may be done by hooking them out, knocking them out, or by raising them to the surface of the fire where they may burn out and crumble. The work of removing a clinker must never be attempted while the engine is working, because in removing it there will be an inrush of cold air, which will cause injury to the firebox sheets and the tubes.

55. **Honeycomb.**—The cause of honeycomb, or flue-sheet clinker, is not known, although different theories have been advanced. However, it has been found that quite generally a leak in the tubes or the firebox sheets accompanies honeycomb, and that when the leaks are repaired the trouble from honeycomb ceases; also, wetting the coal seems to aid in preventing it. Honeycomb in many cases will be prevented, or at least retarded, by carrying a light, level fire and providing an excess of air in the firebox. When it starts to form it should be knocked off the flue-sheet; otherwise it soon will entirely block the tubes and so cause an engine failure.

56. **Station Stops.**—When approaching a station, the fireman should have sufficient coal in the firebox to take care of the fire until the start has been made after the stop and the reverse lever has been hooked up. The last fire should be put in long enough before the throttle is closed for the stop, to allow the gases to be distilled and so prevent smoke while at the station and a waste of fuel. When the stop is made, the fire should be sufficient to carry steam pressure until speed is attained in starting. If, through unlooked-for delay or otherwise the fire needs replenishing before this, put the fire in before the train starts. It is a poor practice to put in a fire while the exhaust is heavy, because the open fire-door will let such a large stream of cold air through the firebox and tubes as will cause leakage of the tubes and sheets.

57. Descending Grades.—In approaching a long down grade where the engine will drift with throttle closed, precautions must be observed to keep the pop from blowing. The fire should be burned down as low as possible without dropping the steam pressure. If there is danger that the pop may open after the throttle has been closed, enough coal should be sprinkled over the fire to prevent this. Also, if necessary, the fire-door may be left on the latch or swung back and forth to prevent popping. While the engine is on the descent is a good time to clean the fire if this is necessary.

58. Waiting on Sidings.—When approaching a siding where a long wait is expected, the fire should be burned down as much as possible without lowering the steam pressure. If the fire needs cleaning, this should be done at once so that there will be time in which to build the fire up into shape again before the train has to start. If the fire does not need cleaning, but the injector is working, it should be kept bright until the water level is obtained. Then the fire should be sprinkled over with green coal and if the engine has dampers they should be closed to keep the pop from blowing. If the engine has no dampers, the fire-door should be placed on the latch. The object should be to avoid popping by keeping the fire only high enough to prevent a drop in steam pressure. The fire should never be allowed to get so low as to lose steam pressure, as leaks are apt to develop.

The fireman should begin to prepare his fire in plenty of time before leaving the siding, so that he will have it built up and in condition to withstand the heavy exhausts of starting the train.

59. Cleaning the Fire.—If the fire is always carried as light as is consistent for the work the engine is doing, the fireman will have the least amount of coal to shovel, and the chances are that he will not have to clean the fire while on the road. If he does have to clean it, the work of cleaning it will be very much less than if a thick, heavy fire were carried. Heavy firing, either before or after leaving, increases the formation of clinkers and so reduces the time that a fire can go

without cleaning. By carrying a light fire, therefore, and taking precautions against the formation of clinker, a fireman can save himself the hard, hot work of cleaning the fire during the run.

Where a train is a long time on the road and the fire becomes dirty and clinkered, it should be cleaned at the first opportunity. The fireman will be well repaid for this labor, as he will get better results with less work and coal, and will avoid leaky tubes.

If an opportunity is not presented during the run for thoroughly cleaning the fire, a small amount at a time should be cleaned as conditions permit. In this way it will often be possible to complete the trip, whereas without doing so a stop would have to be made to enable the fire to be cleaned.

60. Cleaning the Ash-Pan.—It is very important that the ashes be not allowed to accumulate in the ash-pan, and that no live fire be shaken into the pan and allowed to burn there. The temperature in the ash-pan rises rapidly as the pan fills with ashes, thereby greatly increasing the tendency of the ash to melt and form a clinker. If fire is allowed to burn in the ash-pan, not only will clinker form on the grates, but also the grates are very apt to be burned out. Some roads pipe the overflow pipes from the injectors into the ash-pans, so that after the grates have been shaken the injector primer can be started and water sent through the overflow pipe to put out any fire that may have been shaken into the pan.

Some roads equip the ash-pan with steam blowers for the purpose of cleaning. In some cases, one pipe in the center is used, while in other cases two pipes are used, one on each side of the center. The steam blower is not only useful in cleaning out the ashes, but also serves to clean the snow and ice from the pan in winter, thereby avoiding delays necessary to melt the snow and ice by means of a fire.

61. Terminal Stop.—On approaching a terminal station, the engineer should see that there is plenty of water in the boiler and that full steam pressure is carried. The fireman should have enough coal burning on the grates so the hostler

will not be required to put in a fresh fire while the engine is in his charge. There should be a good bed of fire left for the fire cleaners, so that the fire can be cleaned properly.

The last fire put in by the fireman should be fired at a distance from the terminal sufficient to enable the gases to be distilled from the coal before the throttle is closed. The fire should be allowed to burn down so that there will be just the right amount of brightly burning coal for the purposes of the hostler when the train arrives at the station.

62. Summary of Firing Instructions.—The following is a brief summary of the instructions on the hand-firing of locomotives as given in the preceding pages; to obtain the results indicated in the following paragraphs it is assumed that the coal used is of fair average quality and does not require any special method of handling when being fired.

The fireman should be at the roundhouse in ample time to prepare his fire properly for the trip. He should ascertain that he has all the necessary tools used in firing on the engine before leaving the roundhouse and should examine the firebox to see if there are any leaks that would be a detriment to the fire or draft and cause engine to fail to steam. The smokebox door should be examined to see that it does not leak and that the nuts holding it closed are screwed up tight. He should ascertain if the grates can be worked, if the fire is free from clinkers, that the ash-pans are clean, and if the slides can be worked. He should also perform any other additional duties prescribed by the rules of the company.

63. The fire should be built up to the required thickness by adding two or three scoops of coal at a time, and putting the blower on lightly. In order to make a solid bed of fire and avoid the formation of clinkers, additional coal should not be added until the coal already in the firebox has been well burned. The final thickness of the fire will depend on conditions, such as the service the engine is in, the intensity of the draft, quality of the coal, etc., but should be sufficient to insure that the starting and pulling out of the train will not injure the fire when the

engine is being worked at long cut-off. When building up the fire, the injector can be put on, if necessary, to prevent the engine from popping.

64. After the train has been started, the coal should be fired at regular intervals, closing the door between scoopfuls. Two or three scoopfuls of coal well scattered should be about the amount necessary to fire at one time. The fireman should aim to keep a level fire by scattering the coal, a bright fire, and a fire of uniform depth by frequent and light shaking of the grates. The fire carried should be as thin as conditions will permit. Banks, holes, and dead places in the fire, especially next the flue sheet, must be avoided. As a general rule, the tendency is for the fire to burn the heaviest in the four corners of the firebox, along the sides, and next the flue sheet. In this event the fire, instead of being level, should be thicker at these points.

65. Fresh coal should not be added until the fire has burned down to a white heat, if the conditions under which the engine is working permit. The steam gauge should be watched closely for indications of improper conditions in the firebox. When the steam pressure begins to fall under apparently favorable conditions, the fireman should examine his fire for banks, holes, or clinkers. The fireman should make a practice of noticing the condition of the fire during the time the door is open when putting in a fire, and should endeavor to carry a mental picture of his fire at all times. Shake the grates as lightly as possible and often enough to keep the fire clear of ashes and of the correct depth to secure the best results for the conditions under which engine is working. The frequency with which the grates should be shaken will depend on the amount of waste material in the fuel, but ashes should not be allowed to accumulate to such an extent as to render a heavy shaking of the grates necessary. The grates should not be opened up too wide at first, but should be partly opened and closed with short quick jerks. This tends to break up clinkers and avoid the possibility of their being caught in the grates and holding them open. With power grate shakers, if the grates are

frequently moved with the limiting lock in position, it will be unnecessary to throw this lock out and open the grates fully.

66. Endeavor to carry as even a steam pressure as possible when the engine is working. This implies a more or less constant firebox temperature and reduces the tendency of the flues to leak. A high temperature can be maintained by keeping the fire bright, clean, and as thin as conditions will permit, the coal being fired light and often, and well scattered, the door being closed after each scoop.

Except when cleaning the fire, use the rake or hook only when necessary to break up the coke. If the coal is broken up small and fired lightly, very little coke will form and excessive use of the rake can be avoided.

To avoid smoke when shutting off for stations, put in the last fire far enough back so that it is burned down. Crack the blower when putting in a fire at stations, and avoid smoke by firing lightly and putting the fire-door on the smoke notch.

The fireman should learn the road over which he is firing and fire according to the grades. He should let the fire burn down for a meeting or passing point if they have to take the siding, and should know where to prepare for the bottom or summit of a hill, and also know how the engineer is going to work the engine at these places.

The deck and gangways of the engine should be kept clean and free from coal not only to prevent loss by falling off, but also to prevent accidents due to stepping on loose coal.

COMBUSTION

CHEMICAL ELEMENTS AND COMPOUNDS

GENERAL DEFINITIONS

67. Every body or mass of matter is either an element, a compound, or a mixture.

A **compound** is a substance formed by the chemical combination of two or more elements, and therefore can always be decomposed into separate substances. Water, for example, is a compound formed by the chemical combination of the gaseous elements, hydrogen and oxygen, and can be decomposed into these elements by passing a current of electricity through it. Any substance that can be decomposed into other substances is called a compound. Examples of compounds are wood, salt, lime, and the resultant gases of combustion.

68. Such substances as cannot be decomposed or broken up into separate substances by any known means are called **elements.** Silver, for example, is an element, and it is made up of but one substance. The innumerable compounds in the world are really made up of various combinations of a comparatively small number of elements. Some of the more common elements are oxygen, hydrogen, nitrogen, carbon, sulphur, iron, tin, lead, copper, zinc, gold, silver, nickel, and mercury. In the study of combustion, however, only the first six of these elements are of interest to the fireman and are the only ones that will be considered here. The elements are generally represented by *symbols,* which usually are the first letter of their names: thus, *O* stands for oxygen; *H,* for hydrogen; *N,* for nitrogen; and *C,* for carbon. A compound is expressed by combining the separate symbols of its elements; such a combination is called its *chemical formula.*

69. Atoms of elements combine to form molecules of elements and of compounds. An **atom** is defined by chemists as the least part of an elementary substance that can enter into or be expelled from a compound. Atoms of the same element are always of equal weight and volume, but they may differ in weight or volume, or in both, from atoms of other elements. They never exist in a separate state, but always combine with one or more atoms to form a molecule.

A **molecule** is the smallest quantity of an element or compound that is capable of a separate existence. It can be divided into its atoms only by a chemical process.

ELEMENTS

70. **Oxygen.**—Oxygen is one of the principal parts of the air, forming about one-fifth of it; the other four-fifths is nitrogen. These elements are not chemically combined, but are mixed together so that no chemical action is necessary to separate them. Should some element for which oxygen has a greater affinity, or liking for, be introduced into the mixture, the oxygen will leave the nitrogen and make a chemical combination with the other element. A chemical action takes place when oxygen forms a compound with any other element. If this element is a fuel, the chemical action is called combustion.

Combustion, or burning, cannot begin unless oxygen is present, nor can burning continue unless oxygen is available. Oxygen is therefore necessary to start combustion, and also to support it. During combustion, oxygen is the only element in the mixture known as the atmosphere that can be used in burning coal.

71. **Hydrogen.**—The element called hydrogen is the lightest substance known. It is a colorless, tasteless, odorless gas. In coal it exists in combination with carbon in the form of certain compounds called **hydrocarbons.** When the coal is thrown into the firebox, the heat to which it is subjected causes these hydrocarbon compounds to be driven off in the

form of gases, the chief one being the gas known as **methane**, or **carbureted hydrogen.**

72. Nitrogen.—Four-fifths of the air is nitrogen, which is a tasteless, colorless, odorless gas that will not support life when breathed alone and that will not sustain combustion, or burning. It is well that so much of the air is nitrogen, for if the greater part of the air were oxygen, any fire, when once started, would burn so rapidly and fiercely that it could not be controlled. The large percentage of nitrogen acts as a sort of check on burning and so, to increase the rate of burning, it is necessary to create a draft, so as to circulate more air and so bring more oxygen in a given time to the point where the burning is going on.

73. Carbon.—The element that forms the larger part of coal is carbon. After the gases have been driven off from coal, the hard coke remaining consists largely of pure carbon. At ordinary temperatures it will not combine with any of the other elements to form chemical compounds. But if raised to a high temperature it will combine very readily with oxygen, for which it has a strong liking, or affinity.

THE COMPOUNDS, COAL AND WOOD

74. Coal.—Coal is a compound that consists of carbon, hydrogen, oxygen, nitrogen, sulphur, and iron in connection with other substances. The part of the coal that burns consists of the carbon, hydrogen, and sulphur; but as the sulphur is looked upon as an impurity in coal, and as its percentage is small when compared with the percentages of carbon and hydrogen, only the carbon and hydrogen will be considered as the parts of the coal that produce heat by their burning. The compounds of hydrogen and carbon in coal, or the hydrocarbons, are of a very complex nature and exist as gases, the principal one of which is methane, and also as a heavy tarry liquid. This tar, when heated in the firebox, is decomposed into carbon and hydrocarbon gases of different kinds. As the actions that take place in the burning of these hydro-

carbons are too complicated to be within the scope of this paper, the burning of methane alone will be considered in connection with the combustion of coal.

75. The two main classes of coal are hard coal, or anthracite, and soft coal, or bituminous coal. It is customary to state the composition of a coal by giving the percentages of fixed carbon, volatile matter, moisture, and ash that it contains. All coal contains moisture, which may be there when the coal is mined or may get into it during or after transportation. The ash is the refuse that is left after the coal is burned, and consists of clay, sand, iron, and other substances that do not burn. The **volatile matter** includes all the gases and vapors that are driven off when a sample of dry coal is heated without burning. The **fixed carbon** is the carbon contained in the solid mass of coke that remains after the gaseous constituent, or volatile matter, has been driven off.

As a very general average, the composition of anthracite may be taken as follows:

Constituents	Per Cent.
Fixed carbon	83
Volatile matter	4
Moisture	3.5
Ash	9.5

The average composition of bituminous coal will fall within the following limits:

Constituents	Per Cent.
Fixed carbon	40 to 61
Volatile matter	27 to 39
Moisture	1 to 17
Ash	6 to 17

Carbon, it will be observed, is the chief constituent of coal. It forms the solid part, or that which remains after the volatile matter has been distilled off by heating. The ash is made up of the incombustible impurities, such as slate, bone, iron, and some sulphur. The iron and sulphur in coal are often found combined in the form of a compound called *iron pyrites,* which

TABLE II

COMPOSITION AND HEATING VALUES OF AMERICAN COALS

(*United States Geological Survey*)

State	Nearest Town	Name of Seam	Kind	Grade	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Calorific Value B. T. U.
					Per Cent.					
Alabama.......	Horse Creek	Horse Creek	B	L N	1.55	32.10	53.71	12.64	.73	12,958
Alabama.......	Carbon Hill	Jagger	B	L N P	2.58	33.15	51.74	12.53	1.02	12,449
Alabama.......	Garnsey	Underwood	B	R	2.72	20.46	53.46	14.36	.55	12,461
Alabama.......	Belle Ellen	Youngblood	B	R	6.43	28.56	52.09	12.92	1.08	12,395
Alabama.......	Lehigh	Black Creek	B	R	5.51	25.05	53.28	16.08	1.40	11,932
Alabama.......	Dolomite	Pratt	B	R	2.86	25.80	63.98	7.36	.59	14,440
Arkansas......	Bonanza	Jenny Lind	S B	L	.74	16.26	73.66	9.34	1.90	13,961
Arkansas......	Denning	Spadra	S B	S	1.79	14.36	73.52	10.33	1.68	13,402
Arkansas......	Coal Hill	Denning	S B	L S	1.28	12.82	73.69	12.21	2.01	13,406
Arkansas......	Huntingdon	Huntingdon	S B	L	1.17	17.83	68.12	12.88	1.27	13,460
Arkansas......	Midland	Hartshorn	S B	L	5.47	16.27	66.57	11.69	2.02	12,690
California......	Tesla	Tesla	L	R	18.51	35.33	30.67	15.49	3.05	8,105
California......	Stone Canyon		B	R	4.86	47.74	41.03	6.37	4.26	12,727
Colorado	Lafayette	Laramie	B L	R	13.49	37.11	43.03	6.37	.58	10,546
Colorado	Sopris	Sopris	B	R	1.26	31.03	53.39	14.32	.64	12,929
Colorado	Bowen	Walsen	B	R	1.41	31.52	49.16	17.91	.68	12,127
Colorado	Rugby	Cameron	B	S	1.73	35.72	48.36	14.19	.81	12,366
Colorado	Berwind	Berwind	B	R	1.66	33.24	51.57	13.53	.64	13,019
Colorado	Oak Creek	Yampa	B	R	6.69	36.68	45.88	10.75	1.51	11,561
Colorado	New Castle		B		2.73	38.09	53.60	4.98	.54	13,372
Florida........	Orlando	Peat, air dried	P		21.00	51.72	22.11	5.17	.45	8,127

Georgia........	Menlo	Little River	B	L	3.80	15.88	65.83	14.49	1.27	12,791
Illinois........	O'Fallon	Belleville, No. 6	B	L N	6.28	38.92	41.08	13.72	4.25	11,448
Illinois........	Marion	Cartersville, No. 7	B	R	5.96	30.29	52.16	11.59	1.77	12,103
Illinois........	Coffeen	Pana, No. 5	B	R	5.13	32.68	47.46	14.73	4.45	11,158
Illinois........	Collinsville	No. 7	B	R	10.83	36.24	39.75	13.18	4.53	10,816
Illinois........	Cartersville	No. 7	B	R L	8.86	31.25	48.23	11.66	2.46	11,902
Illinois........	Livingston	No. 5	B	R	12.25	33.76	41.66	12.33	4.42	10,719
Illinois........	Zeigler	No. 7	B	L	10.72	29.86	50.06	9.36	.91	11,686
Illinois........	Herrin	No. 7	B	L	7.78	29.85	52.39	9.98	1.32	11,959
Indiana........	Terre Haute	No. 6	B	R	12.79	35.45	39.67	12.09	3.18	10,899
Indiana........	Seelyville	No. 3	B	R	7.88	36.85	41.07	14.20	5.14	11,146
Indiana........	Linton	No. 4	B	R	13.58	32.07	46.20	8.15	.91	11,419
Indiana........	Linton	No. 5	B	R	10.30	36.31	41.64	11.75	4.23	11,218
Indiana........	Brazil	{Bottom Bed / Brazil Block}	B	S N	16.91	26.85	38.87	17.37	1.89	9,524
Indiana........	Maxville	No. 7	B	L	5.24	37.83	45.73	11.20	3.56	12,085
Iowa..........	Laddsdale	Middle	B	L S	5.21	31.76	46.51	16.52	5.20	11,392
Iowa..........	Marion Co.	Big Vein	B	R	4.25	37.02	41.74	16.99	5.20	11,129
Iowa..........	Altoona	Third	B	L	4.52	40.96	38.99	15.53	6.83	11,356
Iowa..........	Centerville	Mystic	B	L	10.03	37.27	41.22	11.48	4.46	11,227
Iowa..........	Chariton	Lower	B	R	9.22	32.71	44.52	13.55	3.42	10,989
Kansas........	Fleming	{Lower / Weir-Pittsburg}	B	R	3.74	33.11	50.01	13.14	4.34	12,404
Kansas........	Scammon	Weir-Pittsburg	B	R	2.50	33.80	51.25	12.45	5.68	12,900
Kansas........	Jewett	Weir-Pittsburg	B	L	9.04	29.69	45.55	15.72	3.72	11,142
Kansas........	West Mineral	Weir-Pittsburg	B	L N	4.10	31.65	53.71	10.54	3.77	12,895
Kansas........	Atchison		B	L	3.57	37.00	46.80	12.63	8.33	12,337
Kentucky......	Straight Creek	Straight Creek	B	L	1.92	36.56	57.08	4.44	1.24	14,319
Kentucky......	Earlington	No. 11	B	L	5.36	38.99	46.27	9.38	3.72	12,539
Kentucky......	Barnsley	No. 9	B	R	5.85	36.90	46.96	10.29	3.60	12,292

TABLE II—*Continued*

State	Nearest Town	Name of Seam	Kind	Grade	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Calorific Value B. T. U.
					Per Cent.					
Kentucky......	Wheatcroft	No. 11	B	R	2.54	36.08	46.79	14.59	4.67	12,294
Kentucky......	Sturges	No. 13	B	R	5.46	30.99	55.63	7.92	1.18	13,239
Kentucky......	McHenry	No. 9	B	N	8.70	35.00	47.34	8.96	3.14	12,078
Kentucky......	Big Black Mt.	High Splint	B	L	1.60	36.03	58.56	3.81	.69	14,324
Kentucky......	Near Paintsville	No. 1	B	R	5.12	36.49	55.63	2.76	.57	13,743
Maryland......	Frostburg	Big Vein	S B	R	.74	18.14	73.83	7.29	.86	14,555
Maryland......	Near West'nport		S B	R	2.33	16.11	68.43	13.13	1.49	13,255
Missouri.......	Bevier	Bevier	B	R	9.14	34.53	39.02	17.31	5.30	10,451
Missouri.......	Higbee		B	R	12.92	33.64	39.82	13.62	5.03	10,548
Missouri.......	Novinger		B	N	16.36	29.12	35.01	19.51	3.53	9,007
Missouri.......	Barnett		B	R	5.39	44.91	44.47	5.23	5.55	13,529
Missouri.......	Huntsville		B	L	2.49	45.44	38.79	13.28	6.34	12,213
Montana......	Bridger	Bridger	L	S	8.56	32.36	45.69	13.39	.54	10,685
Montana......	Red Lodge	No. 1	L	S	7.34	37.92	42.17	12.57	1.10	10,269
Montana......	Bear Creek	No. 2	L	S	8.21	37.98	47.67	6.14	1.47	11,422
New Mexico...	Blossburg	Raton	B	R	2.72	31.85	50.86	14.57	.69	12,539
New Mexico...	Gibson	Weaver	B L	L S	10.86	35.14	46.90	7.10	.64	11,435
New Mexico...	Van Houten	Raton	B	R	3.45	32.00	47.82	16.67	.73	11,893
North Dakota.	Williston	Cedar Coulee	L	R	16.70	37.10	39.49	6.71	.63	9,491
North Dakota.	Lehigh	Lehigh	L	R	15.42	38.73	33.61	12.24	2.02	9,061
Ohio..........	Mineral City	No. 5	B	L	4.49	40.55	47.43	7.53	2.93	13,291
Ohio..........	Bellaire	No. 8	B	R	4.14	39.30	47.18	9.38	3.96	13,381

Ohio..........	Near Wellston	No. 4	B	R	7.71	38.32	42.02	11.95	4.61	11,515
Ohio..........	Shawnee	No. 6	B	R	9.90	33.66	44.86	11.58	1.81	11,279
Ohio..........	Danford	No. 7	B	L	6.65	33.94	48.86	10.55	3.13	12,179
Ohio..........	Dixie	Hocking, No. 6	B	R	7.55	38.00	46.08	8.37	2.84	12,128
Ohio..........	Bradley	No. 8	B	L N	3.53	37.45	49.90	9.12	3.47	13,072
Oklahoma	Panama		S A	R	.64	14.29	76.66	8.41	1.24	14,083
Oklahoma	Henryetta	Henryetta	B	L	3.87	35.73	50.05	10.35	1.99	12,620
Oklahoma	Hartshorne	Hartshorne	B	R	1.70	37.19	49.79	11.32	1.56	12,969
Oklahoma	Edwards	McAlester	B	R	3.45	37.45	47.82	11.28	3.67	12,469
Oklahoma	Lehigh	Lehigh	B	L	4.91	37.79	43.90	13.40	4.02	11,389
Pennsylvania ..	Ellsworth	Pittsburgh	B	L N	1.47	34.83	57.59	6.11	.89	14,155
Pennsylvania ..	Hastings	D	S B	R	.36	22.67	68.78	8.19	1.65	14,062
Pennsylvania ..	Wehrum	B	S B	R	.34	18.12	71.45	10.09	3.88	14,193
Pennsylvania ..	Connellsville	Pittsburgh	B	R	.97	29.09	60.85	9.09	.90	13,952
Pennsylvania ..	Ehrenfield	Lower Kittanning	S B	R	.63	17.32	75.22	6.83	.97	14,706
Pennsylvania ..	White	Upper Freeport	B	R	1.09	28.71	57.87	12.31	1.56	13,406
Pennsylvania ..	Loydell	Miller	S B	R	.38	16.10	74.69	8.83	1.55	14,267
Pennsylvania ..	Huff	Pittsburgh	B	R	.91	29.03	59.57	10.49	1.03	13,738
Pennsylvania ..	Kimmelton	Lower Kittanning	S B	R	.50	17.75	70.12	11.63	2.09	13,783
Pennsylvania ..	Scranton		A	S	2.08	7.27	74.32	16.33	.77	12,472
Rhode Island..	Cranston		G A	R	.42	5.02	75.11	19.45	.07	11,212
Tennessee	Fork Ridge	Mingo	B	R	1.87	33.93	52.71	11.49	1.63	12,942
Tennessee	Brushy Mt.	Petros	B	R	1.35	35.13	53.32	10.20	3.38	13,421
Tennessee	Coalmount	Sewanee	B	L	1.36	27.96	56.22	14.46	.96	12,843
Tennessee	Gatliff	Regal Block	B	R	2.25	35.68	54.79	7.28	1.02	13,480
Tennessee	Waldensis	Lower Sewanee	B	R	1.02	28.43	55.69	14.86	.80	12,886
Tennessee	Gatliff	Log Mountain	B	R	1.95	36.97	54.05	7.03	1.01	13,734
Texas..........	Hoyt		L	R	9.76	37.51	42.77	9.96	.70	10,228
Texas..........	Olsen		L	R	9.88	36.77	43.65	10.30	1.30	10,287
Texas..........	Crockett		L	R	13.40	42.75	29.00	14.85	1.04	9,358
Utah..........	Price		B		2.34	43.68	48.92	5.06	.57	13,671

TABLE II—*Continued*

State	Nearest Town	Name of Seam	Kind	Grade	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Calorific Value B. T. U.
					Per Cent.					
Virginia.......	Pocahontas	No. 3	S P	R	1.63	17.17	75.34	5.86	.75	14,672
Virginia.......	Tom's Creek	Upper Vanner	B	L	.87	32.36	62.19	4.58	.68	14,796
Virginia.......	Blacksburg	Big Seam	A	P	4.80	10.12	67.05	18.03	.63	11,961
Virginia.......	Darby	Darby	B	L	2.40	37.64	55.54	4.42	.81	14,224
Virginia.......	Richlands	No. 4	B	R	.65	24.28	64.77	10.30	1.27	13,963
Washington....	Renton		B L	R	5.20	36.54	45.68	12.58	.80	11,291
Washington....	Roslyn	Roslyn	B	L	1.88	36.97	48.73	12.42	.38	12,751
Washington....	Carbonado	No. 3	B	R	4.66	29.07	50.31	15.96	.45	12,132
Washington....	Taylor	No. 4	B	R	6.20	34.20	41.37	18.23	.69	10,888
West Virginia..	Kingmont	Pittsburgh	B	R	1.35	36.92	55.36	6.37	.90	14,164
West Virginia..	Clarksburg	Pittsburgh	B	R	1.12	37.65	52.60	8.63	2.56	13,937
West Virginia..	McDonald	Sewell	S B	R	.68	23.28	70.91	5.14	.91	14,765
West Virginia..	Winifrede	Winifrede	B	R	1.50	37.16	56.39	4.95	1.35	14,247
West Virginia..	Rush Run	Fire Creek	S B	R	.64	21.74	72.53	5.09	.66	14,942
West Virginia..	Big Sandy	No. 8	S B	R	.62	18.05	74.38	6.95	.69	14,733
West Virginia..	Page	Ansted	B	R	1.17	31.87	62.95	4.01	.91	14,821
West Virginia..	Powellton	Powellton	B	R	1.01	29.53	62.67	6.79	.80	14,171
West Virginia..	Bretz	Bakerstown	B	R	1.00	27.99	62.68	8.33	1.49	14,225
West Virginia..	Bretz	Upper Freeport	B	R	.98	28.72	61.87	8.43	.90	14,139
West Virginia..	Monarch	Cedar Grove	B	R	1.58	35.21	55.50	7.71	1.24	13,757
West Virginia..	Coalton	Roaring Creek	B	L	.65	29.20	59.97	10.18	.99	13,828
West Virginia..	Springhill	Black Band	B	L	1.95	36.24	54.42	7.39	.66	13,694
Wyoming......	Hanna		B L	R	9.21	45.27	42.04	7.48	.29	11,009
Wyoming......	Rock Spring		B L	R	6.00	38.69	51.68	3.63	.86	12,519
Wyoming......	Cambria		B	R	2.73	37.61	37.40	22.26	4.17	10,364
Wyoming......	Kemmerer		B L	R	8.68	41.31	46.49	3.52	.55	11,621
Wyoming......	Monarch		B L	R	17.69	37.96	39.56	4.79	.63	10,355

is largely responsible for the formation of clinkers. Soft coal contains a much smaller percentage of fixed carbon than hard coal and a correspondingly greater amount of volatile matter. The parts of the coal that burn and give off heat in burning are, taken together, known as the **combustible.**

76. Calorific Value.—The value of a coal as fuel depends on the quantity of combustible that it contains and on the **calorific value,** or **heating value,** which is the quantity of heat developed by the complete combustion of one pound of the coal. The calorific value cannot be measured in pounds or gallons, like solids or liquids, because heat is not a substance; therefore, it is necessary to measure the heat developed by the effect it produces, and this is commonly done by noting the number of degrees rise of temperature produced in a known quantity of water by the heat.

77. If a pound of water at 39.2° F. is heated until its temperature is one degree greater, or 40.2° F., the quantity of heat added to the water is one **British thermal unit,** abbreviated B. T. U. This is the unit by which heat is usually measured, just as the inch is the unit for measuring short lengths and the gallon for measuring liquids. Thus, the British thermal unit is the quantity of heat required to raise one pound of water one degree Fahrenheit. So, to find the calorific value of a fuel, it is only necessary to burn a pound of it and observe the rise of temperature that the heat of burning produces in a known weight of water. For example, suppose that the heat developed by burning a pound of a certain coal was sufficient to heat 200 pounds of water from 40° F. to 108° F., or an increase of 68° F. The heating value of that coal then must be $68 \times 200 = 13{,}600$ B. T. U. In other words, the product of the rise of temperature and the weight of water is the heating value per pound.

78. The calorific value of a pound of carbon burned completely is 14,500 B. T. U. and of hydrogen is 63,200 B. T. U. Coals, being made up of carbon and hydrogen in varying proportions, have different heating values, depending on the relative amounts of carbon and hydrogen. In recent years it has

TABLE III COMPOSITION AND HEATING VALUES OF CANADIAN COALS

Field	Town	Mine	Seam	Grade	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Calorific Value B. T. U.
					Per Cent.					
Alberta:										
Edmonton.........	Strathcona	Strathcona		L	22.7	41.0	47.6	11.4	.4	10,728
Edmonton.........	Edmonton	Parkdale		L	22.5	37.8	51.3	10.9	.4	10,908
Edmonton.........	Edmonton	Standard		L	23.5	42.0	49.9	8.1	.4	11,358
Belly River........	Taber	Taber		L	13.0	36.0	49.9	14.1	1.4	11,034
Belly River........	Lethbridge	Galt		L	8.4	37.5	51.5	11.0	.8	11,719
Lundbreck.........	Lundbreck	Lundbreck		R	5.0	30.1	40.2	29.7	1.2	9,810
Frank-Blairmore....	Passburg	Leitch	Bellevue No. 1	R	1.9	27.0	55.1	17.9	.6	12,240
Frank-Blairmore....	Hillcrest	Hillcrest		R	3.0	29.3	55.4	15.3	.6	12,456
Frank-Blairmore....	Lille	Lille	No. 1	R	.9	27.6	56.9	15.5	.8	12,384
Frank-Blairmore....	Bellevue	Bellevue	No. 1	R	1.7	25.0	58.6	16.4	.5	12,474
Coleman...........	Coleman	Denison	No. 2	R	2.0	25.1	55.1	19.8	.4	11,718
Coleman...........	Coleman	Denison	No. 4	R	2.0	23.9	59.9	16.2	.6	12,528
Canmore-Bankhead.	Canmore	A No. 1		R	1.2	17.2	70.5	12.3	.8	13,212
Canmore-Bankhead.	Banff	Bankhead		P	1.0	11.8	76.0	12.2	.6	13,320
Canmore-Bankhead.	Banff			B	1.1	12.6	71.5	15.9	.6	12,672
British Columbia:										
Crows Nest Pass...	Michel	No. 3		L	1.4	24.8	62.7	12.5	.5	13,266
Crows Nest Pass...	Michel	No. 7		L	1.9	22.6	65.5	11.9	.4	13,356
Crows Nest Pass...	Michel	No. 8		L	3.0	24.1	65.7	10.2	.6	13,482
Crows Nest Pass...	Hosmer	Hosmer	No. 2	R	1.7	21.3	63.4	15.3	.3	12,708
Crows Nest Pass...	Hosmer	Hosmer	No. 6	R	2.6	25.6	62.0	12.4	.6	13,086
Crows Nest Pass...	Hosmer	Hosmer	No. 8	R	4.0	28.0	64.5	7.5	.6	13,986
Crows Nest Pass...	Fernie	Coal Creek No. 2		R	2.2	26.3	64.7	9.0	.5	13,822
Crows Nest Pass...	Fernie	Coal Creek No. 5		R	1.6	24.0	65.2	10.8	.5	13,482

Nicola Valley.......	Coutlee	Middlesboro No. 2		R	2.9	39.0	48.1	12.9	.7	12,068
Vancouver Island...	Wellington	Extension		L	1.8	40.1	49.8	10.1	.4	13,158
Vancouver Island...	Nanaimo	Esplanade No. 1	Douglas	L	2.2	41.2	48.5	10.3	.9	12,834
Vancouver Island...	Nanaimo	Esplanade No. 1	Newcastle	L	2.4	41.5	46.6	11.9	1.3	12,474
Vancouver Island...	Cumberland	Union No. 4	Newcastle	L		31.6	56.5	11.9	1.0	12,870
Vancouver Island...	Cumberland	Union No. 7	Newcastle	L		28.0	60.1	11.9	.9	12,978
Vancouver Island...	Suquash	Suquash				34.3	42.7	23.0	1.0	11,106
New Brunswick:										
Grand Lake........	Minto	Kings		L	1.3	32.2	53.4	14.4	5.8	12,888
Nova Scotia:										
Sydney............	Cape Breton	Port Morien	Gowrie	L		34.7	53.0	12.3	6.4	12,708
Sydney............	Glace Bay	No. 7	Hub	L	3.5	36.5	57.6	5.9	2.4	13,860
Sydney............	Glace Bay	No. 9	Harbour	L	2.4	38.6	55.5	5.9	3.7	14,004
Sydney............	Glace Bay	No. 5	Phalen	L	3.4	35.0	59.5	5.5	1.8	14,040
Sydney............	Glace Bay	No. 10	Emery	R	4.0	35.1	53.8	11.1	2.5	13,122
Sydney............	Lingan	No. 12	Lingan	R	4.9	37.3	57.9	4.8	1.8	13,788
Sydney............	Sydney Mines	Sydney No. 1	Main	L	3.5	37.4	55.4	7.2	2.9	13,770
Sydney............	Sydney Mines	Sydney No. 3	Main	L	5.4	39.0	54.3	6.7	2.5	13,680
Inverness.........	Inverness	Inverness		L	9.3	40.0	49.6	10.4	6.0	12,150
Inverness.........	Port Hood	Port Hood		L	4.7	37.1	48.3	14.6	7.9	11,772
Pictou............	Thorburn	Vale	6 Foot	L	2.1	32.1	50.6	17.3	1.0	12,024
Pictou............	Stellarton	Allan Shaft	Foord	R	3.6	33.3	55.4	11.3	.6	13,230
Pictou............	Stellarton	Albion	Third	R		29.8	55.5	14.7	1.4	12,852
Pictou............	Stellarton	Albion	Cage Pit	R	3.6	31.4	58.1	10.5	.9	13,176
Pictou............	Westville	Acadia	Main	L	1.8	26.0	64.8	9.2	.9	13,860
Pictou............	Westville	Drummond	Main	L	1.4	24.7	60.8	14.5	2.5	12,960
Springhill.........	Springhill	No. 2		L	2.8	32.3	58.5	9.2	1.6	13,394
Springhill.........	Springhill	No. 3		L	2.8	33.5	55.0	11.5	1.8	12,996
Joggins...........	Chignecto	Chignecto		L	3.6	41.0	45.7	13.3	6.4	12,150
Joggins...........	River Herbert	Minudie		L	3.8	35.7	48.8	15.5	6.7	11,826
Joggins...........	Joggins	Joggins		L	1.3	36.6	44.8	18.6	5.4	11,592
Saskatchewan:										
Souris............	Estevan	Eureka		R	30.9	40.0	43.2	16.8	.5	9,648

become a general practice to buy coal on a B. T. U. basis—that is, to buy it on the basis of its calorific value expressed in heat units, or B. T. U., per pound, rather than on the grade of the coal or the name of the seam from which it is mined. Table II gives the composition and calorific values of a number of typical coals of the United States and Table III gives similar information for Canadian coals. It is to be noted that coals from the same locality vary considerably in composition and heating value. In these tables the letters used are explained as follows: In the column giving the kind of coal, A indicates anthracite; B, bituminous; B L, black lignite, or subbituminous; G A, graphitic anthracite; L, lignite; P, peat; S A, semi-anthracite; S B, semibituminous. In the column giving the grade of coal, L indicates lump; N, nut; P, pea; R, run of mine; S, slack; and a combination of letters represents a mixture, as, for example, L N refers to a mixture of lump and nut. The letters M S in Table III indicate mine sample; and B indicates buckwheat (anthracite).

In the case of the coals mentioned in Table II, the sulphur in the samples was determined separately; consequently, the sum of the moisture, volatile matter, fixed carbon, and ash is 100 for each kind of coal. In Table III, the sum of the volatile matter, fixed carbon, and ash is 100 for each coal, as the moisture and sulphur were determined separately. On account of this difference in methods of analysis, the values of the corresponding percentages, in the two tables cannot be compared directly.

79. Wood.—As a fuel, wood is divided into two classes: the hard woods, such as maple, oak, hickory, etc., and the soft woods, such as pine, birch, poplar, etc. The value, as fuel, of equal weights of different woods, when equally dry, is very nearly the same. In other words, 1 pound of maple is no better for fuel than 1 pound of pine or poplar, provided that both contain the same percentage of water. Water in fuel is very detrimental, every 10 per cent. of moisture reducing its value as a fuel about 12 per cent.

Wood cut in winter will retain, by the end of the following summer, about 40 per cent. of its water, while, after several

years in a dry place, it still retains from 15 to 20 per cent. of it. If wood that has been thoroughly deprived of all moisture is exposed to the outside atmosphere, it will absorb about 5 per cent. of moisture in 3 days, after which it will continue to absorb moisture until it contains about 16 per cent.; it will then absorb no more.

The chemical composition of the various woods is nearly the same, and is about as follows for ordinary fire-wood:

	Per Cent.		Per Cent.
Carbon	37.50	Nitrogen	.75
Hydrogen	4.50	Water	25.00
Oxygen	30.75	Ash	1.50

Two and one-half pounds of good dry wood is generally assumed to evaporate as much water as 1 pound of good coal. A *cord* of wood consists of a pile 4 feet wide, 4 feet high, and 8 feet long.

MIXTURES

80. Definition.—A **mixture** may consist of two or more elementary substances, or compound substances, or both elementary and compound substances, mixed together, but not combined chemically. For example, gold and silver filings may be mixed together to form a mixture; iron filings and sand mixed together form another example; salt water is another instance of a mixture, while the atmosphere forms, perhaps, the most familiar example of all. Air is a mechanical mixture, consisting of twenty-three parts, by weight, of oxygen to seventy-seven parts of nitrogen. These gases are not combined chemically—they are simply mixed together.

81. Air.—The atmosphere consists of a fluid called **air,** that completely surrounds the earth to an estimated height of about 40 miles. It is held in place by its own weight. The weight of the atmosphere is such that it exerts a pressure of 14.7 pounds per square inch at the sea level—a pressure sufficient to balance a column of mercury 30 inches high, or a column of water 34 feet high. This pressure is sufficient to force the air into all holes, crevices, and porous substances, so

that it penetrates the earth to a considerable depth, its density increasing with the depth.

Ordinarily, pure air has no color, taste, or odor; it consists chiefly of a mixture of 4 volumes of nitrogen and 1 volume of oxygen, or, by weight, of about 3.5 parts of nitrogen and 1 part of oxygen. It is through the medium of the atmosphere that the oxygen so necessary to animal and vegetable life, and to the process of combustion, is furnished in its free state. At 62° F., 13.14 cubic feet of air weighs 1 pound.

THEORY OF COMBUSTION

GENERAL PRINCIPLES

82. Definition.—Combustion, or burning, as it is properly called, is a very rapid chemical combination of oxygen of the air with any combustible material, producing both heat and light. Oxygen has a very strong affinity for most elements, and especially for carbon, with which it combines very rapidly whenever they come in contact with each other at a sufficiently high temperature. The more rapid the combination, the greater is the quantity of heat given off in a unit of time, and consequently the higher the temperature produced.

83. The combustible substances in coal, wood, oil, etc. are carbon and hydrogen. The combustion of fuel, therefore, is the rapid chemical combination of the carbon and hydrogen in the fuel with the oxygen of the air. In order to bring about combustion, three conditions are necessary: first, the combustible or fuel; second, air containing the oxygen needed to support combustion; and third, a sufficiently high temperature to cause the combustible elements to start to burn. The temperature to which a combustible substance must be heated before it will begin to burn is called the **igniting temperature.** Each substance has its own igniting temperature, that of coal being in the neighborhood of 1,800° F.

84. Illustration of Combustion.—A familiar illustration of the process of combustion is furnished by the lighting

and burning of a match. The match may be considered as the fuel, the oxygen is supplied by the air, and the substance forming the tip of the match is employed to bring the wood of the match to the igniting temperature. The igniting temperature of the chemical on the tip of the match is much lower than that of the wood; therefore, when the match is struck on a rough surface the friction between the head and the rough surface generates enough heat to raise the temperature of the chemical to the igniting point and so sets it on fire. Its burning in turn raises the temperature of the wood to the igniting temperature, or about 1,000° F. This takes place almost instantly, with the result that the wood and the oxygen start to combine, and the match is said to burn. It will be noticed, however, that the entire surface of the match is not ignited at one time, but that it first begins to burn next the chemical on the tip, and gradually burns toward the other end of the match. The reason for this is that only a portion of the wood near the flame is heated to the igniting temperature. This takes fire, and heats another portion of the wood nearest it to the igniting temperature, which in turn burns, and so on gradually until the match is consumed.

85. Products of Combustion.—The combustible elements in coal are principally carbon and hydrogen, for both of which oxygen has a strong affinity; however, the affinity of oxygen for hydrogen is stronger than that of oxygen for carbon. The result is that when the hydrocarbons in fuel are broken up into carbon and hydrogen, the hydrogen burns first, because the oxygen unites with it in preference to uniting with the carbon. The burning of the hydrogen in coal results in the formation of water, whose chemical formula is H_2O. This formula indicates that two atoms of hydrogen combine with one atom of oxygen to form one molecule of water, or H_2O; but as the firebox is at a high temperature, the water thus produced is converted into steam by the heat and escapes through the stack, along with the smoke and other gases. Steam is therefore the product of the combustion of the hydrogen contained in the fuel.

86. When carbon burns, it may produce either or both of two different gases, depending on the conditions under which combustion takes place. Suppose that the amount of air supplied to the coal is sufficient to furnish two atoms of oxygen for every atom of carbon in the fuel. Then the carbon will combine with the oxygen in the proportion of one atom of carbon to two atoms of oxygen, and each of these combinations results in the formation of a molecule of CO_2, which is the chemical formula of **carbon dioxide.** This is a colorless, tasteless, odorless gas. Whenever there is enough oxygen present, carbon will always burn to carbon dioxide. This gas represents the product of the complete combustion of carbon; that is, the carbon has combined with as much oxygen as it can possibly take up. Carbon dioxide is a dead gas; that is, it cannot be burned, because it is the result of a combustion that is complete.

87. If the quantity of air supplied is too scanty, the result will be incomplete combustion of the carbon. Under such conditions there will not be enough oxygen present to supply each atom of carbon with two atoms of oxygen, and so these two elements will unite in another proportion. Each atom of carbon will unite with one atom of oxygen to form one molecule of **carbon monoxide**, the chemical formula for which is CO. In other words, the carbon combines with only *half* as much oxygen as when it burns to carbon dioxide. Therefore, carbon monoxide is the product of the incomplete combustion of carbon. It also is a colorless, tasteless, odorless gas; but it is different from carbon dioxide because it can be burned. If, after carbon monoxide is formed, it is mixed with a fresh supply of air at a sufficiently high temperature, it will take up additional oxygen and burn to carbon dioxide. This means that each molecule of CO will take up one more atom of O, or oxygen, and thus become CO_2, or carbon dioxide.

88. There is another way in which carbon monoxide may be formed. If a deep fire is carried on a grate, some of the carbon at the bottom of the fire will burn and produce carbon dioxide and this gas will be carried by the draft up through the fire. In the heart of the fire bed there will be a layer of hot

fuel that will be practically pure coke, which consists of carbon without any gases in it. The carbon-dioxide gas, rising and mixing with this hot coke, is broken up, or decomposed, by the heat, into carbon monoxide and free oxygen. The oxygen thus set free combines with some of the carbon in the coke and forms carbon monoxide, so that the net result is that the carbon dioxide is converted into carbon monoxide by taking up additional carbon. This is a very common action in the fire on a locomotive grate. As the monoxide rises into the firebox, however, it is mixed with fresh air admitted above the fire and so is burned to carbon dioxide before it can escape to the stack.

89. As carbon monoxide is capable of being burned, it should not be allowed to escape; otherwise, it will carry away combustible matter and so cause a direct loss. The object should be to burn all carbon to carbon dioxide, as by so doing the greatest possible amount of heat is obtained from the combustion. If a pound of carbon is given enough air to enable it to burn to carbon dioxide, it will yield 14,500 B. T. U. But if the air supply is cut down so that it can burn only to carbon monoxide, the amount of heat developed will be only 4,400 B. T. U. In other words, the incomplete combustion of carbon results in a direct loss of 10,100 B. T. U. In the first case, one part of carbon combines with two parts of oxygen and forms carbon dioxide, which produces a great amount of heat; and in the second case, one part of carbon combines with only one part of oxygen and forms carbon monoxide, producing only one-third as much heat. With half enough oxygen it does only one-third the work that it could do with sufficient oxygen, and oxygen is free—it costs nothing.

90. To change one pound of carbon into the best heat-producing gas takes, theoretically, about 152 cubic feet of air. If half this amount is supplied, the pound of carbon will only use the oxygen contained in 76 cubic feet of air, and will only be one-third as valuable. In each case the same amount of coal will be used, but in the latter case, on account of imperfect burning, only one-third the amount of heat will be generated,

and so only one-third the amount of water will be changed into steam, and steam is what is wanted. At the same time an excess of smoke will be made, and smoke is not wanted. Oxygen is free, while coal costs money; therefore, enough oxygen should be supplied by the air to make perfect combustion and save coal.

91. To follow up this process, it is readily seen that if all the carbon, both fixed and gaseous, could be supplied with all the oxygen needed to change it into carbon dioxide, it would evaporate the same amount of water into steam that 3 pounds of carbon would in case it had so small a supply of oxygen that it could only make carbon monoxide. With a full supply of oxygen, a saving of two-thirds of the coal would, theoretically, take place. But it never happens that all the carbon changes into the very hot gas, as the fluctuating conditions of the supply of coal and air to the fire prevent ideal proportions, so that the fireman must be content with saving as much as possible.

AIR REQUIRED FOR COMPLETE COMBUSTION

92. Carbon.—To burn carbon completely, twelve parts of it, by weight, must combine with thirty-two parts of oxygen; therefore, for every pound of carbon burned, $32 \div 12 = 2.67$ pounds of oxygen must be supplied. As only about 23 per cent. of the air is oxygen, $2.67 \div .23 = 11.6$ pounds of air must be supplied for every pound of carbon consumed; that is, 11.6 pounds of air contains 2.67 pounds of oxygen, and, theoretically, should supply sufficient oxygen to completely burn 1 pound of carbon. The remainder of the 11.6 pounds of air, viz., 8.93 pounds of nitrogen, passes off with the $2.67 + 1 = 3.67$ pounds of carbon dioxide, as the products of combustion.

93. Hydrogen.—The hydrogen of the fuel combines in the proportions, by weight, of two parts of hydrogen to sixteen parts of oxygen, forming water, which, of course, is in the form of vapor. One pound of hydrogen therefore requires $16 \div 2 = 8$ pounds of oxygen for complete combustion. Since

TABLE IV AIR REQUIRED FOR COMBUSTION OF VARIOUS SUBSTANCES

Combustible	Weight of Oxygen Required to Burn 1 Pound of Combustible Pounds	Quantity of Air at 60° F. Required to Supply the Necessary Oxygen*		Products of Combustion Pounds
		Pounds	Cubic Feet	
One Pound of				
Carbon, burning to carbon dioxide	2.670	11.60	152	3.670 carbon dioxide and 8.93 nitrogen
Carbon, burning to carbon monoxide	1.335	5.80	76	2.335 carbon monoxide and 4.465 nitrogen
Carbon monoxide, burning to carbon dioxide	.570	2.48	33	1.570 carbon dioxide and 1.91 nitrogen
Hydrogen	8.000	34.80	457	26.80 nitrogen and 9 water
Methane (carbureted hydrogen)	4.000	17.40	230	2.745 carbon dioxide, 13.405 nitrogen, and 2.25 water
Average coal	2.530	11.00	140	2.980 carbon dioxide, 8.52 nitrogen, and .45 water
Wood	1.400	6.08	80	1.830 carbon dioxide, 6.08 nitrogen, and .546 water
Petroleum	3.460	15.00	197	3.170 carbon dioxide, 11.55 nitrogen, and 1.28 water

*To determine the quantity of air, in cubic feet, from the weight, in pounds, multiply by 13.14.

each pound of air contains .23 pound of oxygen, $8 \div .23 = 34.8$ pounds of air will be required for the complete combustion of 1 pound of hydrogen. The products of combustion will be $34.8 - 8 = 26.8$ pounds of nitrogen, and $8 + 1 = 9$ pounds of water.

94. Carbon Monoxide.—The combustion of 1 pound of carbon, to form carbon monoxide, requires but half as much oxygen as would be required to form carbon dioxide; therefore, but half the air is required. Since it requires 2.67 pounds of oxygen, or 11.6 pounds of air, to burn 1 pound of carbon to carbon dioxide, to burn it to carbon monoxide would require 1.335 pounds of oxygen, or 5.8 pounds of air, and the products of combustion would be 2.335 pounds of carbon monoxide and 4.465 pounds of nitrogen.

95. Carbon Dioxide.—Carbon monoxide, in burning to carbon dioxide, combines with oxygen in the proportions, by weight, of twenty-eight parts of carbon monoxide to sixteen parts of oxygen. One pound of carbon monoxide therefore requires $16 \div 28 = .57$ pound of oxygen, or $.57 \div .23 = 2.48$ pounds of air, for complete combustion. The products of combustion in this case are: $1 + .57 = 1.57$ pounds of carbon dioxide, and $2.48 - .57 = 1.91$ pounds of nitrogen.

The theoretical quantities of oxygen and of air necessary for complete combustion of various combustibles, together with the products of combustion in each case, are given in Table IV.

HEAT OF COMBUSTION

96. When carbon burns to carbon dioxide, it combines with the greatest amount of oxygen possible, and therefore produces its greatest quantity of heat; when it burns to carbon monoxide, it combines with but half the oxygen possible, and produces less than one-third the heat that would be generated were it burned to carbon dioxide. This is shown in Table V, which gives the total number of heat units produced by the complete combustion of various combustibles.

By completely burning the carbon, 14,500 heat units is produced, while if it is only burned to carbon monoxide, only

TABLE V

CALORIFIC VALUES OF VARIOUS COMBUSTIBLES

Combustible	Total Heat of Combustion of 1 Pound of Combustible B. T. U.
One Pound of	
Hydrogen	62,000
Carbon, burned to carbon monoxide	4,400
Carbon, burned to carbon dioxide	14,500
Carbon monoxide, burned to carbon dioxide	10,100
Methane (carbureted hydrogen)	23,500
Coal (average composition)	14,100
Wood	7,950
Petroleum	21,000

4,400 heat units is produced; that is, 10,100 heat units is wasted for every pound of carbon incompletely burned.

TEMPERATURE OF COMBUSTION

97. Theoretical Temperatures.—In Table V is given the total quantity of heat generated in burning 1 pound of a certain fuel. In Table IV is given the weight and nature of the products of combustion.

The quantity of heat mentioned in Table V will heat the gaseous products of combustion to a certain temperature, depending on their weight and on the number of heat units necessary to raise 1 pound of the gases 1° F. Of course, as the weight and nature of the products of combustion differ for different fuels, the temperatures due to their combustion will differ.

The theoretical temperature of combustion of the fuels in Table VI has been calculated on the assumption that just

enough air for complete combustion is supplied, no allowance being made for losses of heat. These theoretical temperatures are never attained in practice, for the following reasons: Combustion is seldom complete; excess of air is always supplied; fuel is never entirely consumed; heat is lost by radiation; and moisture present in the fuel absorbs some of the heat.

TABLE VI

THEORETICAL TEMPERATURES OF COMBUSTION

Combustible	Resulting Temperature of Combustion Degrees Fahrenheit
Hydrogen	5,750
Carbon, burning to carbon dioxide	4,872
Carbon, burning to carbon monoxide	2,668
Carbon monoxide, burning to carbon dioxide	5,367
Methane (carbureted hydrogen)	9,624
Seasoned wood	2,867
Average bituminous coal	4,080
Average anthracite coal	4,170
Coke or charcoal	4,350

PROCESSES OCCURRING IN THE FIREBOX

98. Tearing-Down Process.—There are two processes constantly going on in a locomotive firebox, one of which is called the *tearing-down process* and the other the *building-up process*. The **tearing-down process** is the breaking up of the fuel into its elements, and requires heat. The **building-up process** is the recombination of the elements separated from the fuel during the tearing-down process with the oxygen of the air to form new compounds, and produces heat. Oxygen will not unite with compounds, but only with elements. Coal is a compound consisting chiefly of carbon and hydrogen,

some of the carbon being combined with the hydrogen to form the volatile matter, or hydrocarbons, the remainder being the fixed carbon. The hydrocarbons must be broken up or separated into their elements, carbon and hydrogen, before oxygen will unite with them. The fixed carbon, as it does not exist in combination with any other element, will burn as soon as it is heated to its igniting temperature.

99. The breaking down or separation of the hydrocarbons, as well as the heating of the fixed carbon to its igniting temperature, requires heat. Therefore, when coal is thrown on the fire, it first absorbs heat. The moisture that may be present in the coal in its natural state, or moisture due to wetting down the coal, is first evaporated, after which the hydrocarbon gases begin to pass off at a temperature of about 400° F. The driving off of these gases continues until the coal is heated to about 900° F., when the greater part of the gases will be given off, the fixed carbon of the coal being left on the grates. As already explained, the hydrocarbon gases are in a compound form, being made up of free carbon and hydrogen, and in this form will not burn. They must be torn down, or separated into their elements, carbon and hydrogen, before burning is possible, and this process requires a far higher temperature than is necessary to distill the gases from the coal. The temperature necessary to break up the hydrocarbon gases into their elements is about 1,800° F., and assuming that the firebox is at this temperature, the hydrocarbon gases are separated into their elements, free carbon and hydrogen. The iron pyrites that may be present in the coal are also heated and separated into iron and sulphur. This completes the tearing-down process, which is accomplished by the expenditure of heat. The building-up process, which results in the formation of heat, will next be considered.

100. Building-Up Process.—It will be assumed first that the conditions in the firebox are such as to insure perfect combustion, which means that the elements present combine in the correct proportions to insure that the maximum temperature will be generated. As already stated, the building-up process

refers to the combination of the elements separated from the fuel, during the tearing-down process, with the oxygen of the air to form new compounds, heat being evolved during the recombination. If the firebox temperature is maintained at or above the igniting temperature of hydrogen and carbon, there will be a combination of oxygen with the hydrogen and carbon set free by the tearing down of the hydrocarbons. When oxygen combines with carbon and hydrogen under the above conditions, certain results always occur in accordance with certain fixed laws. Each atom of carbon under favorable conditions combines with two atoms of oxygen and forms an entirely new compound, known as carbon dioxide, represented by the chemical formula CO_2; and one atom of oxygen combines with two atoms of hydrogen and forms steam, which, when cooled, becomes water, indicated by the chemical formula H_2O. This completes the burning of the carbon and hydrogen of the methane, the only hydrocarbon that will be considered, the products of combustion being carbon dioxide and water vapor.

101. The conditions favorable to the burning of the methane will also result in the breaking up and burning of the other hydrocarbons of the fuel. In order to break up the hydrocarbons, it is necessary to maintain the firebox temperature above 1,800° F.; otherwise, these gases will not be separated into their elements, and will pass off unburned, thus wasting a valuable heat-producing part of the fuel. The carbon and hydrogen will burn at a lower temperature than that required to break up the gases in which they are combined, the igniting temperature of the former being about 930° F. and of the latter about 1,200° F. The remaining carbon, or fixed carbon, of the fuel remains on the grates until consumed, and assuming that there is a high enough temperature and a sufficient supply of oxygen, it unites with oxygen in the same proportion as the free carbon, to form carbon dioxide.

102. During the burning of the hydrocarbons and the fixed carbon, the iron pyrites present separate into the elements sulphur and iron. The sulphur then unites with oxygen and forms a gas known as sulphur dioxide, and the iron combines

with oxygen and forms iron oxide. This latter substance is molten when hot, and in combination with the ashes and other impurities in the coal is largely responsible for clinkers. Although the iron pyrites burn, yet the amount of heat produced by their combustion is small in comparison to the trouble they make in forming clinkers.

103. The tearing down of the hydrocarbon gases into their elements, carbon and hydrogen, and their recombination or building up with oxygen, practically occur instantaneously and if desired may be considered as one and the same event. A small percentage of heat is required to break the fuel into its elementary parts in comparison with the heat produced by the same elements combining with oxygen to form the compounds carbon dioxide and water. These compounds are products of combustion and are gases. If the fuel were composed of carbon and hydrogen only, as in the case of natural gas, for example, and during burning these elements combined completely with oxygen, the gases from burning would be invisible.

104. The fixed carbon of the coal and the carbon of the hydrocarbons do not always burn completely. If there is not enough oxygen present so that each atom of carbon can combine with two atoms of oxygen in the building-up process, some of the carbon will combine with oxygen in the proportion of one atom of carbon to but one atom of oxygen and form another colorless compound gas known as **carbon monoxide,** represented by the formula CO. The heat produced during the formation of carbon monoxide is about one-third as much as is produced when carbon burns to carbon dioxide. The unconsumed carbon that escapes due to the absence of oxygen with which to combine is white hot when in the firebox, but when it cools it turns black and forms smoke. Black smoke is then the unburned carbon of the hydrocarbon gases, and represents a serious fuel loss.

105. Fuel-Bed Actions.—Experiments have shown that the fuel bed on which the fixed carbon burns may be divided into three zones, as illustrated in Fig. 4, known as the oxida-

tion, reduction, and distillation zones. As the air passes from the ash-pan through the grates, the oxygen combines with the carbon of the coal and forms carbon dioxide, generating all the heat due to this union. This action occurs in the oxidation zone, which extends three or four inches above the grate line.

The carbon dioxide, after leaving the oxidation zone, passes through the layers of coke in the reduction zone and there each molecule of carbon dioxide takes up another atom of carbon and is reduced to two molecules of carbon monoxide. As the formation of carbon dioxide results in the liberation of heat, so in its reduction or breaking down in the reduction zone it absorbs heat, with the result that a cooling action takes place in

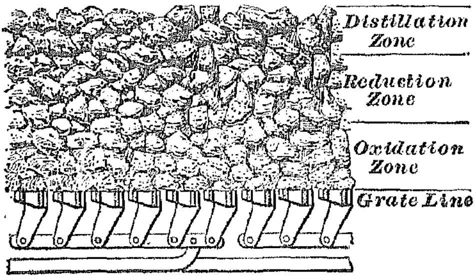

Fig. 4

this zone. The carbon monoxide formed in the reduction zone rises into the distillation zone, where it mingles with the gases that are being distilled, or driven off, from the green coal by the heat, and the mixture of gases rises into the firebox. If there is not sufficient oxygen present to unite with them and burn the carbon monoxide to carbon dioxide, it will pass away in an unburned condition with a resulting loss of heat. If sufficient oxygen is present above the fuel bed, the carbon monoxide will combine with another atom of oxygen and again form carbon dioxide. To burn bituminous coal properly, then, air for the combustion of a portion of the coke can be supplied through the grates, while a sufficient quantity for the combustion of the gases and the upper layers of coal should be admitted above the fire.

106. Proper Air Supply.—The proper supply of air to the fire is one of the most important matters connected with economical firing. It takes about 160 cubic feet of air to supply oxygen for the complete burning of 1 pound of ordinary soft coal, and as each scoopful of coal weighs from 14 to 20 pounds, it will take from 2,200 to 3,200 cubic feet of air to supply the oxygen necessary for its complete combustion. But it is not enough to take in only just sufficient air to furnish the oxygen needed to burn the carbon to carbon dioxide and the hydrogen to water. Every particle of carbon and hydrogen must be surrounded by a liberal supply of oxygen to insure complete combustion, and so 250 cubic feet of air, or nearly 19 pounds, has been found to be about the right amount for a pound of coal, or from 3,500 to 5,000 cubic feet of air for each scoopful. A box car 36 feet long, inside, by 8 feet wide and 8 feet high holds 2,300 cubic feet, which will give some idea of the vast amount of air that must pass through the firebox for each scoopful of coal fired.

107. Quantity of Water Evaporated.—In ordinary locomotive service 7 pounds of water evaporated by 1 pound of coal is a fair average duty; it is possible to raise this amount to 11 pounds. A gallon of water weighs about $8\frac{1}{3}$ pounds. So, if 1 gallon of water is evaporated by the heat developed by burning 1 pound of coal, the results obtained are above the average.

COMBUSTION OF COAL

108. Bituminous Coal.—Coal is a compound substance, consisting chiefly of carbon and hydrogen, in which elements practically its entire heating properties lie. If these are completely burned, the coal will produce its greatest quantity of heat; on the other hand, if they are not completely burned, part of the heat that the coal should produce in burning will pass off as unburned gases and smoke.

When 100 pounds of average bituminous coal is heated, the hydrogen is driven off, taking some carbon with it, in combination, forming 30 pounds of carbureted-hydrogen gas, and

leaving behind about 55 pounds of solid carbon. Thus, for every 100 pounds of coal there is about 55 pounds of solid carbon and 30 pounds of carbureted hydrogen to be burned, the remaining 15 pounds being waste, partly in the gaseous form and partly as solid matter. This means that the coal has .55 fixed carbon and .3 volatile matter. About three-tenths, by weight, of the coal is carbureted-hydrogen gas, which, as seen in Table VI, makes the hottest fire of the fuels there given. The temperature at which this gas breaks up into its elements is rather high, however (about 1,800° F.), and if any part of the firebox is cooled below this, part of the gases will pass away unburned, causing a great waste of heat.

109. Fresh coal, when thrown on the fire, absorbs heat, which raises its temperature and drives off the hydrogen and a portion of the carbon, combined in various chemical unions known as hydrocarbons, of which methane, or carbureted hydrogen, is one. Before burning takes place, this preparatory process of decomposition always occurs, and the products then burn in a certain regular order; the gases burn first, combining with the oxygen of the air to form water and carbon dioxide, while the coke burns last, combining with oxygen to form carbon dioxide.

110. Quantity of Air Required.—For every pound of coal burned in a firebox, enough air must be supplied to furnish sufficient oxygen for the complete combustion of .3 pound of carbureted-hydrogen gas, and .55 pound of carbon. Since, according to Table IV, 152 cubic feet of air is necessary to supply sufficient oxygen to completely burn 1 pound of carbon, it will be seen that $.55 \times 152 = 84$ cubic feet, nearly, must be supplied in burning .55 pound. To completely burn .3 pound of carbureted hydrogen, $.3 \times 230 = 69$ cubic feet of air must be supplied. So that, to completely burn 1 pound of coal, $84 + 69 = 153$ cubic feet of air must be supplied.

This is the theoretical quantity of air required, and it is calculated on the assumption that the air is so intimately mixed with the carbon and gases of the fuel that all its oxygen combines with the fuel. Practical experience, however,

teaches us that the air does not mix very thoroughly with the combustible parts of the coal in the firebox, some of it passing through the tubes and up the stack, without having an opportunity to part with its oxygen. If, therefore, only the theoretical amount of air were admitted to the firebox, it would not supply sufficient oxygen to completely burn the coal, and thus heat would be wasted.

Practical experience in locomotive work, in fact, seems to indicate that about 250 cubic feet (nearly 19 pounds) of air per pound of coal is necessary to secure complete combustion when admitted in the proper manner.

111. If too much air is admitted to the firebox, it wastes heat in two ways: (1) The extra air is heated in the firebox and carries a great deal of heat with it as it escapes through the stack at a high temperature. (2) In order that this increased volume of gases and air may pass through the tubes in a given time, they must acquire a greater velocity, and consequently they will have less time in which to impart their heat to the water.

The effect of admitting too much air to the firebox can very readily be seen by opening the fire-door, for the large volume of cool air thus allowed to pass into the firebox absorbs and carries away so much heat that the steam pressure begins to drop almost at once. The same effect is noticed when holes are allowed to form in the fire.

112. It is impossible to so regulate the thickness of the fire as to allow sufficient air to be admitted through the grates to burn both the coke and also the volatile gases of the coal. The greatest quantity of air is required just after a charge of coal is put in, and, if the fire is sufficiently thin to supply the necessary air at that time, it will supply too much as soon as the gases have been burned. Then, again, as regards facilitating the air supply, the fire would require to be thinnest when the engine was making its greatest effort, and, at such times, the exhaust would be most violent and would tear holes in the fire, through which large quantities of cold air would flow, and so reduce the temperature of the firebox, besides carrying small

pieces of unburned coal into the tubes, thus causing a still further waste.

113. Consumption of Gaseous Products.—It has already been seen that 100 pounds of average bituminous coal produces, in coking, about 55 pounds of solid carbon and 30 pounds of volatile gases. To secure the combustion of the coke or carbon only, would be a comparatively simple matter; it is in the thorough burning of the gases that the chief difficulty is experienced. To burn the gases completely it is necessary: (1) to maintain them at the igniting temperature while in the firebox; (2) to admit sufficient air for their complete combustion; and (3) to admit this air in as small streams as practicable, so that the air and the gases may mix as quickly and completely as possible while in the firebox and at the igniting temperature.

114. The coke can take its own time for burning, as it remains on the grates until consumed. The gases, on the other hand, begin their flight to the tubes the moment they are distilled; they have, consequently, but a fraction of a second in which to mix with the air and burn before they reach the tubes. Time, therefore, has a very important influence on the combustion of the gases, and if they do not have sufficient time to mix completely with the air while in the firebox, and at an igniting temperature, they pass off unconsumed, as no combustion takes place within the tubes. This is why a brick arch aids combustion.

115. Air for the combustion of the gases should not be admitted in large streams, as, for instance, when the fire-door is opened, for in that case it forms a distinct current of cold air that does not mix with the gases but cools them below the igniting temperature, and they pass off unburned. When admitted in small streams, the air is heated quickly and becomes more thoroughly mixed with the gases, and complete combustion is then more nearly secured. The volume of gases is greatest just after coal is put in; the greatest volume of air, therefore, should be supplied at that time, and the supply diminished as the volume of gases generated diminishes.

116. Temperature in Firebox.—The temperature in the firebox must be at about 1,800° F. before the gases will separate into their elements and burn. The maximum temperature attained in the firebox of a locomotive is from 2,000° to 2,500° F., therefore, the difference between the igniting temperature of the gases and the maximum temperature in the firebox is so small, comparatively, that constant care must be exercised to prevent the temperature from falling below 1,800° F. It becomes necessary, therefore, to judge of the temperature in the firebox by the appearance of the fire, for if the temperature is known, the conditions of combustion may

TABLE VII

TEMPERATURES INDICATED BY COLOR OF FIRE

Temperature Degrees Fahrenheit	Appearance	Temperature Degrees Fahrenheit	Appearance
980	Red—just visible	2,010	Dull orange
1,290	Dull red	2,190	Bright orange
1,470	Dull cherry red	2,370	White heat
1,657	Full cherry red	2,550	White welding heat
1,830	Bright red	2,740	Dazzling white heat

be inferred. The appearance of the fire at different temperatures is given in Table VII.

117. The theoretical temperature of combustion of average bituminous coal was given in Table VI as 4,080° F. As just stated, the temperature attained by the combustion of bituminous coal in the firebox of a locomotive is from 2,000° to 2,500° F.; this difference between theoretical and actual temperatures is due to the losses of heat that take place during combustion in the firebox. These losses are as follows: (1) Heat is lost by some of the gases escaping unburned, and by small pieces of coal dropping through the grates or being drawn through the tubes unconsumed; (2) more air is usually supplied than is required for combustion, and, as this

superfluous air and the resultant gases of combustion pass out through the stack, they carry off heat, which reduces the temperature in the firebox; (3) there are losses due to radiation and convection of heat from the boiler; and (4) there is the absorption of heat by the water in the boiler.

The heat absorbed by the water is the chief factor in the reduction of the temperature, and it is due principally to this loss that a higher temperature is not obtained.

SMOKE

FORMATION OF SMOKE

118. Smoke, such as is seen issuing from a chimney or from the smokestack of a locomotive, consists simply of water vapor and the gaseous products of combustion, colored with fine particles of carbon; the blacker the smoke, the more carbon is present as coloring matter.

The formation of smoke takes place as follows: When a quantity of fresh bituminous coal is thrown into the firebox, it absorbs heat so rapidly that the temperature there is reduced below that of ignition of the gases, which, as they are driven off from the coal, appear as a dark-yellow or brownish-colored vapor. This vapor is not the same as that which issues from the smokestack, called smoke, but is carbureted-hydrogen gas, colored by tarry matter, sulphur, and other volatile ingredients.

119. When the carbureted hydrogen attains the proper temperature, it ignites and burns as a flame. The hydrogen unites with oxygen and passes off as water vapor, or steam; the carbon liberated is partly consumed, and partly passes away unconsumed as small particles of solid carbon, called **soot.** It is this latter that colors the escaping gases of combustion and forms what is called smoke.

Had sufficient oxygen been present and in contact with the carbon while its temperature was high enough for them to combine, all the carbon would have been burned and the for-

mation of smoke prevented. Smoke once formed is incombustible at firebox temperatures, as the carbon, or soot, will burn only at a very high temperature.

120. Smoke may be formed, even at high temperatures, if there is not sufficient oxygen present to combine with the carbon as it is liberated; or it may form, when sufficient oxygen is present, if the temperature of the flame is cooled below the igniting temperature of the carbon before the oxygen comes into contact with it. The formation of smoke, due to an insufficient supply of air, may be shown by placing a chimney over a lamp flame and then closing either end. The function of a lamp chimney is to produce an upward draft of air, which is deflected against the flame and furnishes a supply of oxygen sufficient to consume all the carbon while it is at a white heat in the flame. If either end of the chimney is wholly or partly stopped up, the flame will at once begin to smoke, because there is not sufficient oxygen coming in contact with it to burn all the carbon, which therefore passes off as soot or lampblack. As soon as the obstruction is taken from the end of the chimney, however, the current of air through it is resumed, and the smoke ceases.

An example of cooling the flame of a gas below the igniting temperature of the carbon, thereby causing it to smoke when an abundant supply of oxygen is at hand, may be furnished by placing a pan of cold water above the flame. The water will absorb heat from the flame so rapidly that the temperature of the flame will be reduced below the igniting temperature of the carbon, which will consequently pass off unconsumed as soot.

PREVENTION OF SMOKE

121. Carbon, in a gaseous state, before it is liberated from the hydrocarbon gases of the coal, is invisible; but if, after the hydrocarbons have been broken up by the heat, the carbon is not burned, and is allowed to cool, it appears in the solid form as black soot, and forms smoke. The formation of smoke, therefore, can be largely prevented by completely burning all the

carbon as it is liberated from the hydrocarbons, so that none will escape in the solid form as soot. All the carbon can be burned if sufficient oxygen is brought in contact with it as it is liberated, and at the igniting temperature. This is the proper method of preventing the formation of smoke, and it will be found very efficient if the coal is fired in small quantities. For instance, if only small charges of coal are fired at a time, and at regular intervals, smoke will be almost entirely prevented.

A good firebrick arch, properly constructed and applied, assists very materially in the prevention of smoke, because it tends to maintain the temperature at or above the igniting temperature of carbon.

It is not practicable to prevent smoke entirely at all times, as, in order to do so, an excess of air must be supplied, which may be more wasteful than if a little smoke were allowed to form.

OIL-BURNING LOCOMOTIVES

Serial 1299 Edition 1

PETROLEUM

NATURE AND OCCURRENCE

DISCOVERY OF PETROLEUM

1. The marvelous growth of the petroleum industry of the United States is without parallel. In a half century, the annual output has increased from 2,000 barrels to 170,000,000 barrels, which is twice as much as the production of all the rest of the world. The first oil well was drilled in the Oil Creek, Pennsylvania, region by Edwin L. Drake, then a N. Y. & N. H. R. R. conductor, in 1859; today over, 50,000 wells are in operation in a territory that extends from Pennsylvania to California and from Texas to Alaska.

Although the Pennsylvania oil strike occurred in 1859, the Lima, Ohio, strike did not occur until 1885–86. This, however, was followed by the West Virginia strike in 1889; the Lima, Indiana, strike early in the 90's; and then by strikes in Kentucky, Tennessee, the southern extremity of the great Appalachian field, Illinois, Kansas, Texas, Missouri, Indian Territory, Wyoming, Colorado, and California. The real California strike occurred during 1895–96, when the Coalinga and Bakersfield districts were discovered. The output in California for 1910 was 77,697,568 barrels.

2. The great Texas strike occurred in 1901, when the Spindle Top gusher, located near Beaumont and yielding

70,000 barrels a day, was discovered. In 1904, gushers were struck in Louisiana and Indiana and, later, in the Kansas-Indian-Territory fields. These latter fields produced 45,000,000 barrels in 1907. During their second year, the Illinois fields, discovered in 1906, produced over 24,000,000 barrels of oil. The production of oil, for the year of 1910, from the several oil-producing fields of the country is given in Table I.

TABLE I

PRODUCTION OF OIL IN 1910

Oil Field	*Barrels*
Pennsylvania	26,557,079
Indiana	6,671,684
Kentucky	473,526
Illinois	32,984,736
Kansas, Missouri, Oklahoma	59,032,333
Texas	12,823,440
Louisiana, Colorado, Wyoming	847,000
California	77,697,568
Total	217,087,366

USE OF OIL AS A FUEL

3. As the wells of the Appalachian, Lima (Indiana), and other eastern and middle-west fields yielded practically entirely a high-grade oil suitable for illuminating and lubricating purposes, the oil was put through a refining process that netted about 75 per cent. of refined oils and only about 25 per cent. of low-grade residues. The quantity of residues, therefore, was so limited that the oil was not extensively used as a fuel for locomotives until after the great California and Texas oil strikes. The oil from these states is of a lower grade and is

better adapted for fuel than for refining; consequently, after 1901 the supply of fuel oil was so great that oil has been widely adopted as a fuel in locomotive service.

4. **Advantages of Oil Fuel.**—Aside from the relative costs of coal and oil, liquid fuel has many advantages over coal:

1. The oil is stored in big tanks into which it is emptied, from tank cars, by gravity; therefore, only one man is required to take care of all the oil used.
2. A much smaller space is required for storing oil than for coal; therefore, storage help is reduced to a minimum.
3. The cinder pit and all expenses connected therewith is entirely done away with.
4. An oil crane may be suitably placed near each water standpipe so that both water and oil can be taken at the same time.
5. As ordinary ash grates are not used and as there is no diaphragm or netting in the front end of the locomotives, the expense, in fuel, due to the resistance to the draft that is exerted by these parts is entirely done away with. In addition, the first cost and the cost of repairs to these parts are avoided. Besides, a larger exhaust nozzle may be used, with a consequent reduction in back pressure in the cylinders.
6. Large engines are as easy to fire with oil as are small ones; besides, oil firing is very easy on the fireman during warm weather.
7. Full steam pressure can be maintained at all times regardless of grade conditions; hence, more tonnage can be hauled than when coal is used.
8. It is possible to burn 1½ pounds of oil per square foot of heating surface per hour and obtain an evaporation of from 12 to 13 pounds of water from and at 212° F. This will produce 25 per cent. more steam than the maximum rate for coal.
9. The heating value of oil practically is always the same, while the heating value of coal varies greatly, making it difficult to draft engines properly for the changes in coal for best results.

10. There is no clinkering of oil-burner grates, therefore it is not necessary to clean the fires; neither is there a loss of steam pressure due to dirty fire. Consequently, there is no doubling a hill nor loss of time on account of slow speed due to low steam pressure.

11. At terminals, an engine can be turned to go out again in less than ½ hour, for the fire and tubes need no cleaning and there are no cinders to take care of. The only time necessary is that required to take on oil and water.

12. There is no waste of fuel corresponding to cinder loss with coal or to waste through coal dropping into the ash-pan.

13. There is less waste at the safety valve, due to better regulation of the fire with the oil burner.

14. Fewer fires are caused by sparks where ordinary precautions are observed, and greater cleanliness and comfort are afforded the passengers in passenger service, due to the absence of smoke and cinders.

PHYSICAL PROPERTIES OF PETROLEUM

5. Nature of Petroleum.—Petroleum belongs to the bitumen family; it is in no way connected with the coal family, although often wrongfully termed *coal oil*. The **bitumens** are made up of compounds of carbon and hydrogen and occur in the gaseous, fluid, and solid states. The gaseous bitumens are known as **natural gas**. The fluids as **rock oil**, or **naphtha**, a very volatile oil that is as clear as water; **earth oil**, or **petroleum**, a quite volatile fluid with color ranging from brown to black; and **earth tar**, **mineral tar**, **shale tar**, or **maltha**, a viscous, gummy brown-black substance that can be drawn into threads. The solid bitumens as **mineral wax** or **ozocerite**, a yellow to brown-colored mixture of natural paraffins; **mineral pitch**, an elastic black bitumen often called **mineral caoutchouc**, and which in very thin layers is of a brown color; **asphalt**, a brittle, black substance.

The oil as it comes from the oil well is commonly called **crude oil** or **crude petroleum** to distinguish it from the refined petroleum. All crude oil contains a heavy solid **base** or **hydrocarbon residuum**. The Pennsylvania oils have a

heavy paraffin base, whereas the Texas and California oils have a heavy asphaltum base. The paraffin and asphaltum have a peculiar influence on the fluidity of the oil, particularly at low temperatures, as they congeal with the cold and will then require a long time in which to become fluid and completely separate again.

6. Besides the heavy base, crude oil contains a mixture of a number of light, high-grade oils such as **naphtha, benzine, gasolene, kerosene,** and heavier oils suitable for lubricating purposes. As a general rule, the greater the percentage of high-grade products a crude oil contains, the lighter the oil will be. Oils with a paraffin base, as a rule, are lighter than those with an asphaltum base and carry a much greater percentage of high-grade products. The paraffin oils therefore are usually refined and produce about 75 per cent. of high-grade products and only about 25 per cent. of low-grade residuum. This residuum is the tar, pitch, etc. that remain after all the high-grade products are distilled off, and is used for fuel. On the other hand, the oils with an asphaltum base are usually so low in high-grade products that it does not pay to refine them, so they are used as a liquid fuel for generating power. Some of the lighter gravity oils, however, like Oklahoma oil, have to be partly distilled before they can be safely handled and stored for fuel purposes. If the more volatile vapors of such oils are not distilled off, they will give off vapors in sufficient quantities, at ordinary temperatures, to form an explosive mixture that very greatly increases the danger of handling and storing the oil. For safety, therefore, such oils are partly distilled so as to give a flash point of 150° F. or over. Also, crude oil contains properties that corrode iron; most of these properties are removed when the crude oil is slightly distilled.

7. **Flash Point and Burning Point.**—Crude oil gives off vapors at all ordinary temperatures. The rate at which the vapor is given off depends on the amount and nature of the light oils contained and on the temperature of the oil. The nearer the temperature approaches the flash point of the

oil, the more rapidly is the vapor given off. The lowest temperature at which an oil will give off sufficient vapor to cause a flash if a light is applied is called the **flash point** of that oil. Below the flash point, the oil cannot give off vapors fast enough to cause an explosion unless confined. Above the flash point, the vapors are given off fast enough to cause an explosion if mixed with the proper amount of air. A mixture of 1 part of air and 1 part of petroleum vapor will not explode; one of 1 part of air and 3 parts of vapor will give a slight report; but one of 1 part of air and 8 or 9 parts of vapor will cause the most violent explosion. The naphthas are the most volatile of the distilled oils and are extremely inflammable; the gas from them makes very explosive mixtures when mixed with the proper amount of air.

8. The lowest temperature at which an oil will take fire and burn is called the **burning point**, or **fire test**, of that oil. The burning point of petroleum oils is generally from 30° F. to 50° F. higher than the flash-point temperature. Crude petroleum, for power purposes, must have a minimum flash point not lower than 140° F. If it has a lower flash point, it should be distilled until the flash point is raised to 140° F. With a flash point as low as 100° F., the heat of the sun at times will be sufficient to produce vapors at a rate that will form an explosive mixture. Texas oils have greater fluidity and are more volatile than the California oils and have a lower flash point.

9. **Specific Gravity.**—It is important to know the specific gravity of petroleum because, in a way, the specific gravity indicates the amount of light, high volatile constituents in the oil, and, therefore, furnishes an indication of the inflammability and dangerousness of the oil.

By **specific gravity** is meant the relative weight of a volume of oil compared to the weight of the same volume of distilled water at about 40° F. Distilled water at the temperature given is taken as a standard of measure of weight. Specific gravity, therefore, is merely a numerical ratio and represents the number of times a substance is heavier (or

lighter) than an equal volume of distilled water. If, therefore, the weight of 1 gallon of oil is divided by the weight of 1 gallon of distilled water at 40° F., the quotient will be the specific gravity of the oil. If a substance is the same weight as the water, the specific gravity will be 1. When, like the metals, it is heavier than water, the specific gravity will be greater than 1. Where, like oils, etc., it is lighter than water, the specific gravity will be less than 1. The specific gravity of California oils ranges from 1 to .8484. Now, as specific gravity equals the weight of a volume of the oil divided by the weight of the same volume of water, the figures $.8484 = \frac{8484}{10000}$ show that if the oil weighed 8,484 pounds the same volume of water will weigh 10,000 pounds.

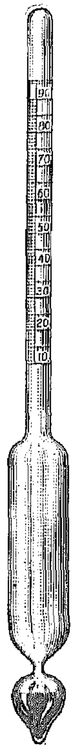

FIG. 1

10. Baumé Hydrometer.—When speaking of fuel oil, the specific gravity is usually referred to simply as the *gravity*, and is given as so much Baumé because the specific gravity is usually measured by a **Baumé hydrometer.** This instrument, which is shown in Fig. 1, was devised by Antoine Baumé, a French chemist, in 1768, to lessen the confusion caused by expressing the specific gravity by means of four figures. It consists of a glass tube in which two bulbs have been blown and which has an arbitrary scale marked upon it. The lower bulb is loaded with mercury to make the tube stand upright in the liquid, while the upper tube is of sufficient volume to make the instrument float. The stem also is hollow and empty. The principle of operation of the hydrometer is that it will sink in a liquid until it displaces a bulk of the liquid just equal to its weight. The lighter the liquid, therefore, the lower will the hydrometer sink in it. The scale for liquids lighter than water is so graduated that when the hydrometer is immersed in distilled water it will sink until the scale registers 10°; therefore, 10° Baumé equals a specific gravity of 1. The higher the gravity in degrees Baumé, therefore, the lighter will be the liquid.

11. In Table II are given the degrees Baumé corresponding to the specific gravity of oils from 1 to .8484 and the weight

TABLE II

SPECIFIC GRAVITY OF VARIOUS OILS

Degrees Baumé	Specific Gravity	Weight per Gallon Pounds	Weight per Barrel of 42 Gallons Pounds
10	1.0000	8.33	349.86
11	.9929	8.27	347.34
12	.9859	8.21	344.82
13	.9790	8.16	342.72
14	.9722	8.10	340.20
15	.9655	8.04	337.68
16	.9589	7.99	335.58
17	.9523	7.93	333.06
18	.9459	7.88	330.96
19	.9395	7.83	328.86
20	.9333	7.78	326.76
21	.9271	7.72	324.24
22	.9210	7.67	322.14
23	.9150	7.62	320.04
24	.9090	7.57	317.94
25	.9032	7.53	316.26
26	.8974	7.48	314.16
27	.8917	7.43	312.06
28	.8860	7.38	309.96
29	.8805	7.34	308.28
30	.8750	7.29	306.18
31	.8695	7.24	304.08
32	.8641	7.20	302.40
33	.8588	7.15	300.30
34	.8536	7.11	298.62
35	.8484	7.07	296.94

per gallon and per barrel of 42 gallons of oil for the different gravities at 60° F.

It will be noticed that 35° Baumé represents a specific gravity of .8484; the scale of the Baumé hydrometer, therefore, directly indicates the relative specific gravity of the liquid *even though it does not read directly in specific gravity.* For liquids lighter than water, however, the Baumé readings may be converted to specific gravity by applying the formula:

$$\text{Specific gravity} = \frac{140}{130 + \text{degrees Baumé at } 60° \text{ F.}}$$

In other words, obtain the Baumé readings when the liquid is at 60° F.; to this reading add 130; and then divide this sum into 140.

EXAMPLE.—What is the specific gravity of a liquid that, at 60° F., has a gravity of 20° Baumé?

SOLUTION.—As the liquid is 20° Baumé, substituting in the formula gives

$$\frac{140}{130+20} = \frac{140}{150} = .9333. \quad \text{Ans.}$$

A comparison of this result with Table II will show that this answer is correct.

12. Expansion of Fuel Oil.—It will be noticed that all the values in Table II are for a temperature of 60° F.; that is, the standard temperature at which the volume, weight, etc., of oil is always calculated. California oils range from 10° to 36° Baumé, whereas the majority of fuel oils range from 13° to 29° Baumé. Heating the oil above 60° F. increases the volume and decreases its gravity and weight per gallon through the expansion of the oil. Decreasing the temperature below 60° F. decreases the volume of the oil and increases the gravity and weight per gallon. The oil changes about 1 per cent. in volume for each 20 degrees change of temperature. In other words, 1,000 gallons of oil at 60° F. will increase 10 gallons or to 1,010 gallons if raised to 80° F. and to 1,020 gallons if raised to 100° F. On the other hand, it will decrease to 990 gallons if reduced to 40° F., and to 970 gallons if reduced to 20° F. That is to say, 1,000 gallons of oil will change 10 gallons in volume for each 20° F. change in temperature. This must be

borne in mind both in buying and in storing oil, so as to make allowance for contraction or expansion of the oil from the temperature at which it happens to be at the time.

BURNING OF FUEL OIL

13. Preparation for Burning.—If a quantity of fuel oil is spilled on the ground and lighted matches thrown in it, the fire of the matches will be extinguished by the oil without igniting the oil. If a piece of lighted waste is plunged into the oil, it, too, will be extinguished. If the waste is floated on the oil, the heat generated by the flame will gradually heat some of the oil and convert it into a gas, which will burn, producing a slow fire with a large amount of black smoke. The oil cannot be quickly burned in large quantities without special preparation, because it cannot be heated and converted into gas quickly from a solid mass. It will smoke badly because the gas does not have sufficient air mixed with it to permit of its being burned smokelessly.

14. To burn fuel oil smokelessly and in sufficient quantities for power purposes, the oil must first be *atomized;* that is, reduced to a fine spray. In that form the oil is quickly heated and converted into a gas and mixed with the proper amount of air because each particle of oil spray is subjected to the high temperature of the firebox while surrounded with air. This results in complete and smokeless combustion if the furnace conditions are favorable.

Economical and smokeless combustion of fuel oil, therefore, requires that the oil be finely divided into spray; that the firebox temperature be high enough to convert instantly the spray into oil vapor or gas; and that the proper amount of air be present and intimately mixed with the gas, to burn the gas completely before it enters the flues. As a rule, the oil is atomized by the use of steam, although air has been used in some instances. Also, some work has been done in the direction of atomizing the oil by mechanical means without the use of steam or air.

15. Heat Value of Fuel Oil.—Crude petroleum is composed of various combinations of carbon and hydrogen, with small amounts of oxygen, nitrogen, and sulphur. As carbon is much heavier than hydrogen, oils rich in carbon are of heavier specific gravity than those rich in hydrogen. This is shown in Table II.

The oil of 10° Baumé is rich in carbon and weighs 8.33 pounds per gallon; whereas, the oil at 35° Baumé is richer in hydrogen and weighs only 7.07 pounds per gallon. There is a difference in weight of 1.26 pounds per gallon or, practically, 53 pounds per barrel in the two oils. As oil is sold by volume at 60° F., a barrel of light oil will contain the same number of gallons as a barrel of the heavy oil, but it will not contain the same number of pounds. At first glance, therefore, it would seem as if the heating value of the lighter oils, per barrel, must be a great deal less than for the heavier oils. In actual practice, however, there is not much difference in the heat derived from actually burning the oils of different gravity.

16. For example, oil at 29° Baumé has only about 89 per cent. of the weight of oil at 13° Baumé, due to the difference in weight. On the other hand, as 1 pound of carbon has a heat value of only 14,500 heat units compared with a heat value of 62,000 heat units per pound of hydrogen, the heat value per pound of the lighter oil at 29° Baumé [19,420 British thermal units (abbreviated to B. T. U.)] is so much greater than that of 13° Baumé oil (18,460 B. T. U.) that the heat value per barrel is only about 9 per cent. less for the 29° Baumé oil. This 9 per cent. difference is considerably reduced in the actual efficiency of burning the oils, for the heavy oils are of such a viscous character that they are not burned as efficiently in general service, owing to the difficulty of properly atomizing the oil for burning. In other words, more steam must be used to atomize this oil properly, and there is a greater tendency to not atomize it properly. Practically, therefore, there is not much difference in the fuel value of oils of different gravity. On the other hand, during cold weather and in cold-weather countries, the lighter oils will have the advantage, as they will

not congeal and become too sluggish to flow as soon or to as great a degree as the heavier oils; consequently, they can be burned more efficiently.

17. A series of evaporation tests on the Southern Pacific Railway, affecting 745 engines, was made with the idea of obtaining the relative heat value of coal and fuel oil for locomotive service. The results of these tests seem to indicate that the relative values vary according to conditions and circumstances, and that the type of engine and the construction and size of the firebox exert a considerable influence. The tests show that on an average, about $3\frac{1}{2}$ barrels of oil are equivalent to a ton of 2,000 pounds of good bituminous coal. This relation, however, depends on the quality of the coal and is different for different localities. The value of the oil is practically the same, whereas the value of the coal varies greatly with the kind and the locality. One pound of fuel oil at 13° Baumé has a heating value of 18,460 B. T. U. per pound, or 6,325,900 B. T. U. per barrel. Oil at 29° Baumé has a heating value of 19,420 B. T. U. per pound, or 5,986,800 B. T. U. per barrel. An oil of average gravity, 21° Baumé, has a heating value of 18,940 B. T. U, or 6,156,300 B. T. U. per barrel. Test records show that under very favorable conditions 1 pound of fuel oil will evaporate from 14 to 16 pounds of water. However, under average working conditions 12 pounds, or $1\frac{1}{2}$ gallons, of water per pound of oil is about the average. One gallon of oil, therefore, will evaporate 12 gallons of water under average conditions.

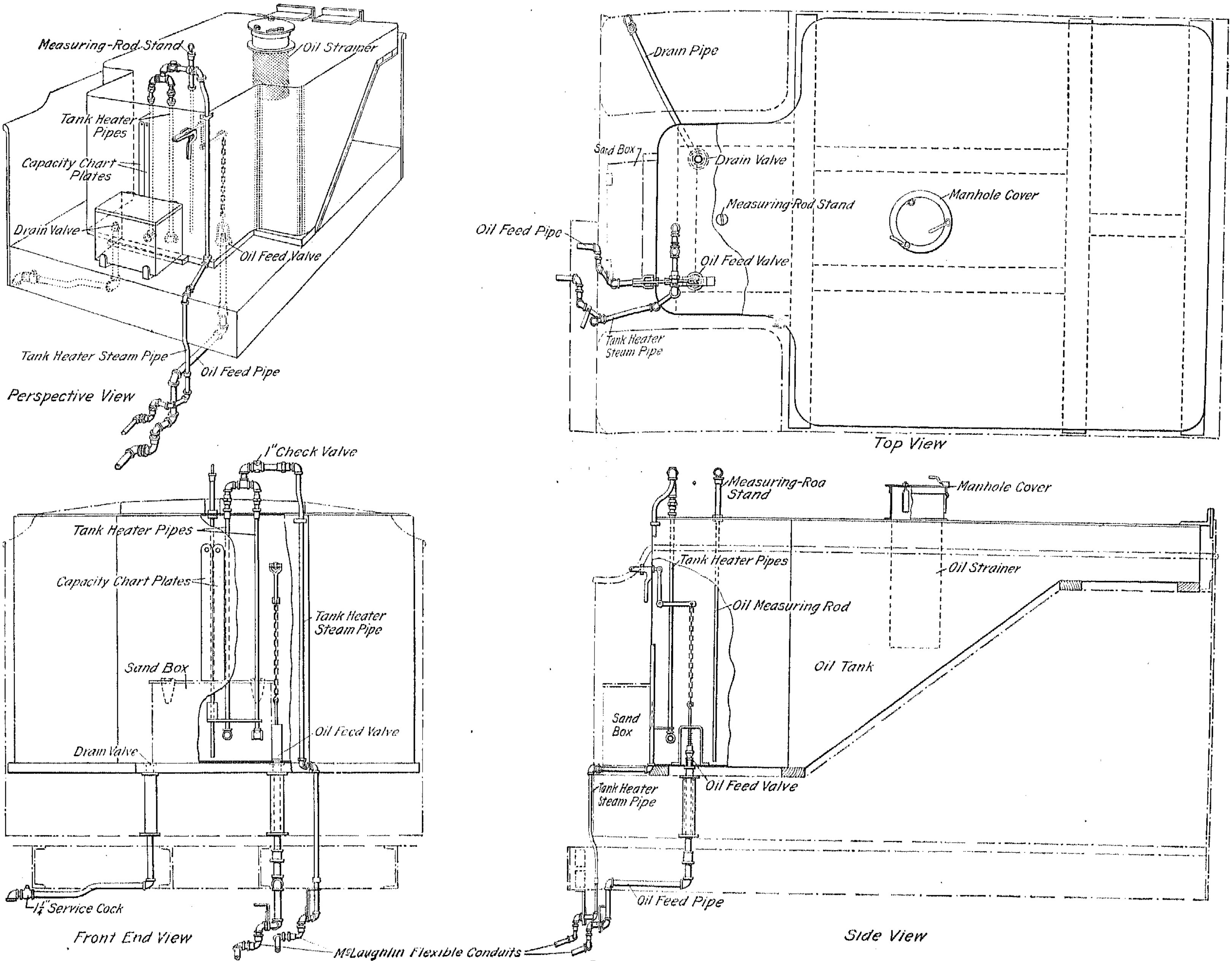

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Fig 2

OIL-BURNING EQUIPMENT

ONE-BURNER SYSTEMS

OIL-TANK ARRANGEMENT

18. **Tank Piping.**—The **oil tank** and the arrangement of the oil piping for the tender of an oil-burning locomotive are illustrated in Fig. 2, in which perspective, top, front-end, and side views of the tank are shown. In the case of rectangular tenders of engines having cylinders 20 inches and over, except Mallet compounds, the oil tank is usually made separate from the tender, though, as shown in the side view, it is made of such size and shape that it will fit into the coal space of the standard form of tender. This construction permits repairs to be made to the oil tank more readily than if the tank were built into the tender. Also, the tank may be elevated to a height that will give a good head for forcing oil to the burner, thus eliminating the necessity of the use of a pump, or of air or steam pressure in the oil tank for that purpose. This arrangement also has the advantage that the tender can be used in connection with a coal-burning engine, if desired, by removing the oil tank.

19. **Oil Manhole.**—The tank is filled through the **oil manhole** shown. A screen, made of No. 4 mesh .085 iron wire, M. M. standard netting, is fitted into the manhole to prevent waste and other foreign matter from getting into the tank. The manhole extends 8 to 12 inches above the top of the tank and is fitted with a cover that can be clamped down tight and thus prevent the oil from splashing over the tender.

20. **Measuring Capacity.**—As shown in Fig. 2, the tank is provided with a **measuring-rod stand** through which the

measuring rod passes. The stand projects about 15 inches above the top of the tank, as shown in the side view. The rod clears the bottom of the tank $\frac{1}{4}$ inch and is graduated, in inches, from the bottom up so as to indicate the depth of oil in the tank.

As shown in the front-end view, two **capacity chart plates** are secured to the front of the oil tank just above the sand box. They are made of $\frac{1}{4}$-inch steel and are painted white, while the letters and stripes are black, as indicated in Fig. 3. These plates give the number of gallons of oil in the tank that correspond to depth of oil, in inches. By noting the depth of oil in the tank by means of the measuring rod and referring to the capacity table, the number of gallons of oil in the tank can be readily determined.

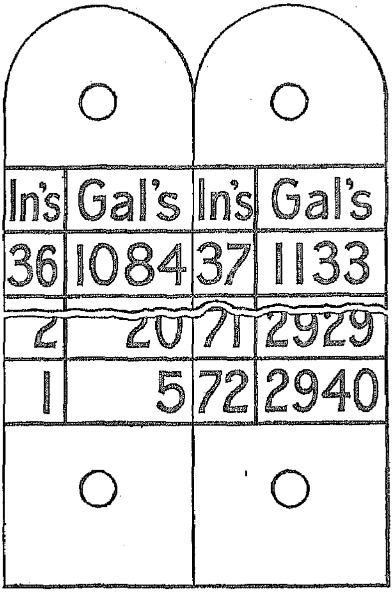

FIG. 3

21. Oil Feed-Valve. The oil passes from the tank through the oil feed-valve and the oil feedpipe to the superheater. As shown in Fig. 2, the feed-valve seat is made to project about $2\frac{1}{2}$ inches above the bottom of the tank, so that there will be space for water in the oil to accumulate in the bottom of the tank without being carried with the oil to the burner.

As shown in Fig. 4, the feed-valve *a* is held closed by a spring *b*. It may be opened or closed by means of the feed-valve lever *c*, to which the valve is connected through a chain and short rod *d*. This rod passes through a stuffingbox in the top or front of the tank. If this stuffingbox is placed in the front of the tank, as shown in Fig. 4, a bell-crank *e* must be placed

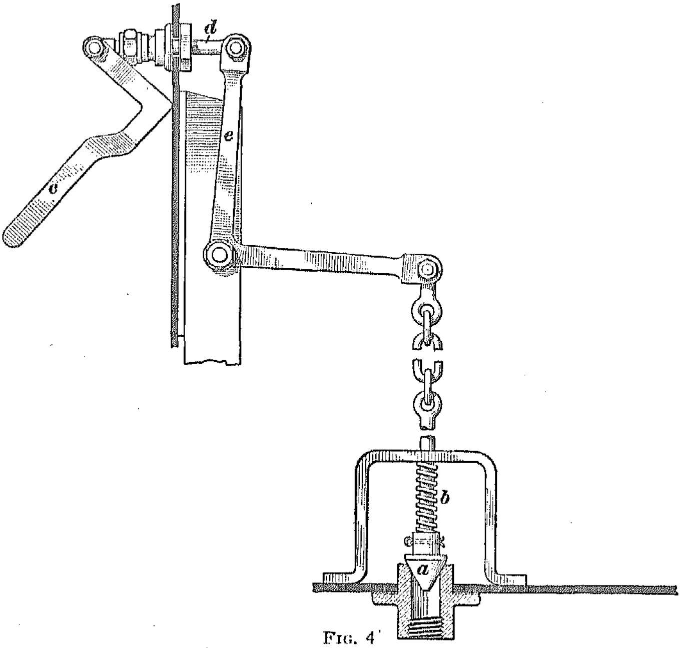

Fig. 4

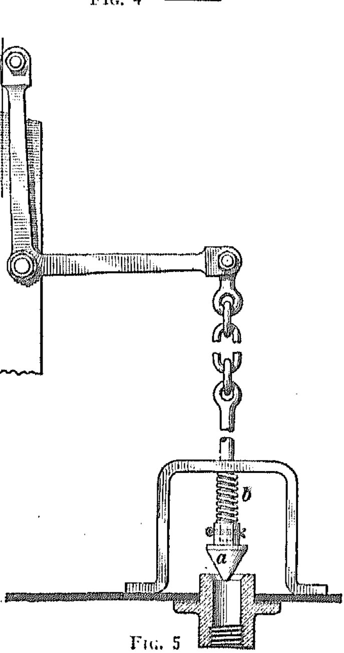

Fig. 5

inside the tank to transform the vertical motion into a horizontal motion. When opened, the valve *a* is raised about 1 inch. The feed-valve lever *c* is then pushed against the tank, as shown in Fig. 5. To close the valve, the lever is pulled away from the tank into the position shown in Fig. 4.

22. Drain Valve.—The **drain valve** is constructed and operated like the feed-valve, except that the drain-valve seat is flush with the bottom of the tank, as in Fig. 6, instead of projecting above it as the feed-valve does in Fig. 4. The drain valve and the drain pipe, Fig. 2, permit water to be drained from the oil tank should the necessity arise.

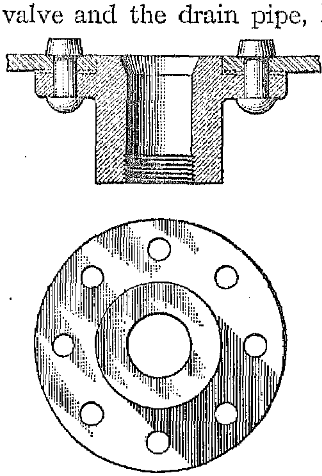

FIG. 6

23. Tank Heater. — The tank-heater pipe leads from the tank-heater valve in the cab of the engine, Fig. 7, and connects with the two heater pipes, as shown in the front-end view in Fig. 2. Each heater pipe is provided with a **T** at its lower end. These **T**'s are at right angles to each other and are placed close to the feed-valve, as shown in Fig. 2, to heat the oil in the vicinity of the oil outlet, so that it will flow freely through the feedpipe. To heat the oil, live steam from the boiler is discharged directly into the oil through the heater pipes. The steam, in heating the oil, condenses and goes to the bottom of the tank, where it accumulates until it is carried off through the drain valve. In some cases the heater pipes are replaced by a heater coil set close to or around the feed-valve outlet, suitable arrangements being made to drain the coil of condensation. In this construction the steam is not discharged directly into the oil. The first method, however, is the one in most general use.

24. Sand Box.—The **sand box** on the forward end of the tender carries a supply of sand that is used in sanding the flues to free them from accumulations of soot.

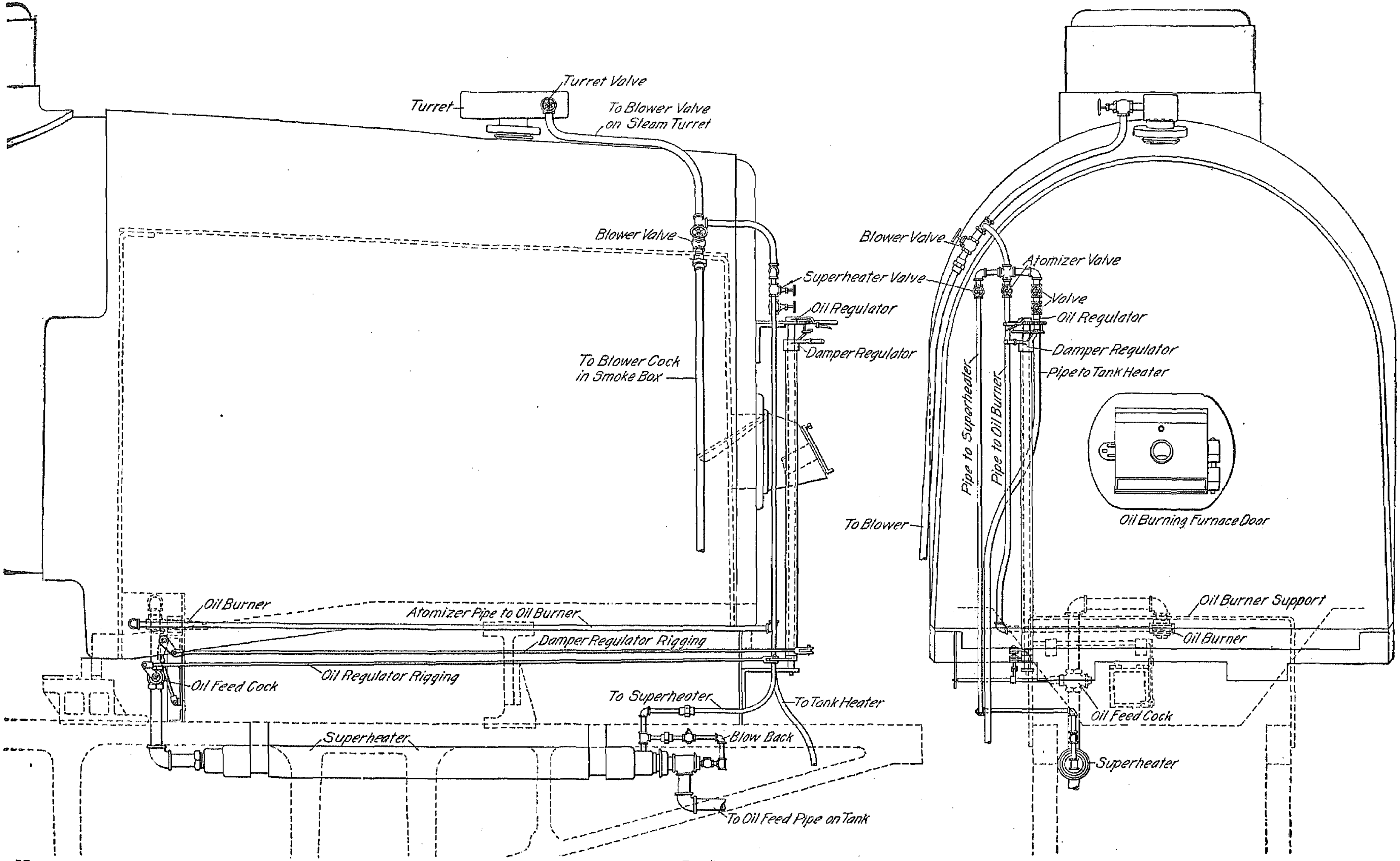

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FIG. 7

25. Engine and Tender Connections.—The connection of the tank-heater pipe and of the oil feedpipe between the engine and tender is made with McLaughlin flexible metallic conduit, as shown in the front-end and side views of Fig. 2. Rubber hose cannot be used for this purpose on account of the destructive effect of the oil on the rubber. A hose failure at this point might be the cause of a fire. McLaughlin flexible conduit is used for all connections between the engine and the tender.

LOCOMOTIVE ARRANGEMENT

26. Piping.—The arrangement of the locomotive piping for burning fuel oil is illustrated in Fig. 7, view (*a*) showing a side view of the piping and of the oil and damper regulation devices, and view (*b*), the piping on the back boiler head. Steam for the oil-burning apparatus is taken from the blower pipe at a point between the blower valve and the turret valve, as shown in (*b*). This pipe divides into three branches. The branch to the left leads through the superheater valve and the superheater, which is shown in (*a*). The middle pipe leads forwards to the oil burner. The pipe to the right leads down to the metallic flexible conduit that connects to the tank-heater pipe. The oil-pipe connections between the tank and the locomotive are quite generally made by the use of some form of the McLaughlin flexible metallic conduit. Rubber hose is not satisfactory for this purpose on account of the destructive effect of the oil on the rubber, and the danger from fire should the hose become defective.

The tank heater warms the oil in the tank sufficiently so that it will flow freely through the piping. However, as it is used intermittently, the temperature of the oil flowing through the pipe, and, consequently, its thickness, vary with the time that has elapsed since the tank heater was last used. Now, in order to have the oil atomize uniformly so as to maintain a uniform fire, it is necessary that the oil should be supplied to the oil burner at a uniform temperature and consistency. This is accomplished by means of the superheating arrangement shown in (*a*).

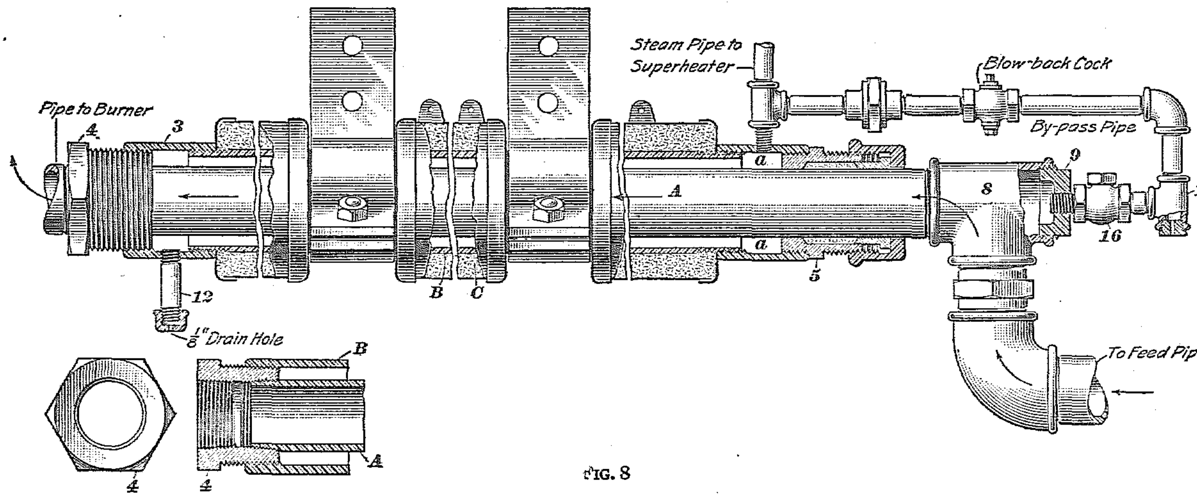

Pipe to Burner
4
3
12
$\frac{1}{8}$" Drain Hole
B
C
Steam Pipe to
Superheater
Blow-back Cock
By-pass Pipe
a
a
A
5
8
9
19
16
To Feed Pipe
B
A
4
4

FIG. 8

27. Oil Superheater.—The construction of the **superheater** is shown in Fig. 8. The inner pipe *A* is of wrought iron and is 7 feet 10 inches long and 2 inches in diameter. One end screws into a special cast-brass bushing *4* that connects the pipe to the burner; the other end screws into the T fitting *a* that connects with the oil feedpipe leading to the oil tank. The oil in passing from the tank to the burner, therefore, must pass through the pipe *A*. A 3-inch wrought-iron pipe *b* 7 feet long incases the inner pipe *A*. One end of this pipe screws into the pipe coupling *3* that connects it with the special bushing *4*; the other end of the pipe is fitted with the stuffingbox *5* through which the inner pipe passes. The stuffingbox makes a steam-tight joint at that end of the 3-inch pipe while at the same time it takes care of any difference in expansion of the two pipes.

28. When the superheater valve is open, steam from the boiler passes through the pipe leading to the superheater and fills the entire space *a* between the two pipes *A* and *B*. This steam heats the inner pipe and, of course, the oil that is passing through it to the burner. The water of condensation is discharged through the drain fitting *12*. Sometimes, as is shown, this fitting is closed by a cap that has only a $\frac{1}{8}$-inch drain hole, so as to prevent the entrance of dirt to the pipes. But in most cases, the cap of the drain fitting is removed and the drain pipe is extended to the back end of the heater, where a valve is supplied to control the discharge from the drain pipe. This brings the discharge of the water and steam back far enough so as not to interfere with the vision of the enginemen, the stuffingbox end of the superheater being toward the rear end.

To prevent undue loss of heat through radiation, the outer pipe *B* is covered with a heat insulating compound *C*; this, in turn, is covered with a galvanized-iron jacket for mechanical protection. The blow-back by-pass pipe connects with the steam-supply pipe to the superheater and is tapped into the plug *9* of the T-fitting *8*. The check-valve *16* will permit steam to pass through into the oil pipe *A*, but will not permit

oil to pass back into the by-pass pipe. The purpose of the by-pass is to permit of steam pressure being admitted into the oil pipe in the event of the feedpipe or the burner becoming stopped up, so as to blow the obstruction back into the oil tank or out of the burner, and thus clear the obstruction. The superheater should be firmly secured to the fire-pan or to the engine frame in such a way as to reduce to a minimum the vibration at the pipe connections.

29. Operation of Blow-Back Device.—The **blow-back device**, shown in Fig. 7 (*a*) and Fig. 8, is intended for use in case of an obstruction occurring in the burner or in the oil

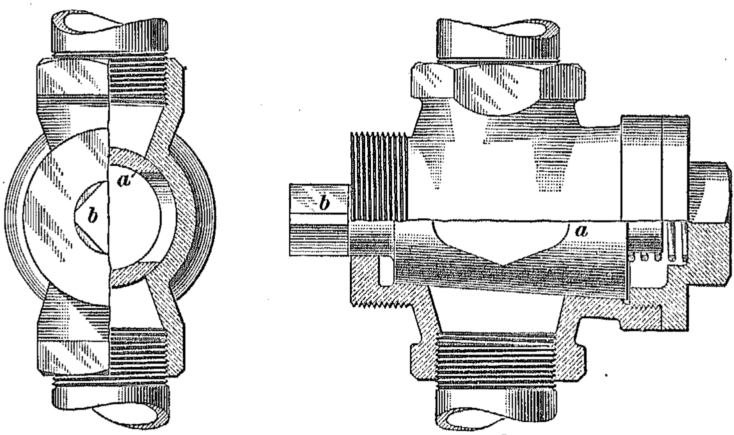


FIG. 9

feed-valve or pipe. Also, it may be used as a heater in case the tank heater becomes inoperative.

The burner may be blown out as follows: Close the tank valve, open the regulating valve wide, close the superheater drain cock, open the blow-back cock, and open the superheater valve just a little until all the oil is burned out of the pipe; then open the valve wide to blow the obstruction out of the burner.

To blow out the oil feedpipe to the tank, close the regulating valve and the superheater drain cock; open the oil feed-valve and the blow-back cock and open the superheater valve

sufficiently to blow the obstruction back into the oil tank. This same method is used to heat the oil in the tank when the tank heater is not operative. Since the heating is done through the oil feedpipe, it must be done when the engine is standing, so that the dampers can be closed tight and the fire can be put out.

The blow-back cock must always be fully closed except when the blow-back feature is in use. Leakage past the cock will make the feed of the oil to the burner irregular and must be prevented. It will be indicated by steam escaping through the T fitting *19*, Fig. 8.

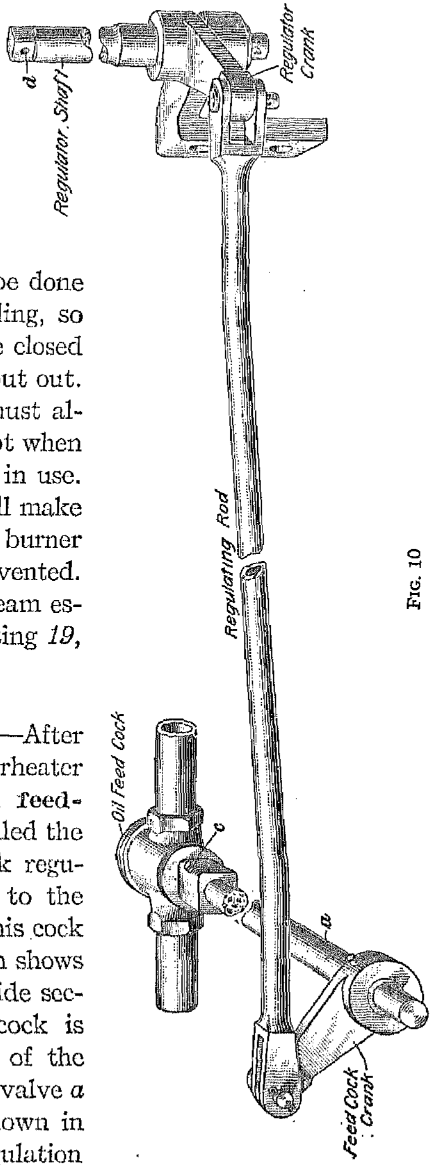


FIG. 10

30. Oil Feed-Cock.—After flowing through the superheater the oil passes to the **oil feed-cock**, Fig. 7 (*b*), often called the **forcing valve**; this cock regulates the flow of the oil to the burner. The details of this cock are shown in Fig. 9, which shows an end view (*a*) and a side sectional view (*b*). The cock is made of brass; the form of the opening through the plug valve *a* is made of the shape shown in order to afford a closer regulation of the oil to the burner. The valve is operated through the stem *b* that is attached to the oil-regulator rigging.

31. Oil-Regulator Rigging.—A perspective view of the **oil-regulator rigging** that operates the oil feed-cock is shown in Fig. 10. The shaft *a* has a socket on one end that fits on the stem *b*, Fig. 9, of the oil feed-cock and is secured to it by means of the taper pin *c*. The shaft, in turn, is fastened to the *feed-valve crank* by a taper pin and the crank is connected to the *regulator crank* by means of the *regulating rod*, as shown. The regulator crank is welded to the end of the *regulator staff*. This is a solid-steel bar that extends up to the oil regulator, Fig. 7 (*b*), which is placed in the cab convenient to the fireman's seat. The staff extends through the lever of the oil regulator and is secured to it by a solid-steel taper pin that passes through the pinhole *d*, Fig. 10. Therefore, turning the regulator lever turns the staff and its crank, which operates the regulating rod and the oil feed-cock crank and, therefore, the oil feed-cock. The regulator crank is 5 inches in length, whereas the feed-cock crank is but 4 inches long; consequently, turning the regulator crank through 80° causes the feed-cock crank to turn through 90°, the amount necessary to open the feed-cock wide. After passing through the feed-cock, the oil flows direct to the burner, as shown in Fig. 7 (*a*).

32. Oil Regulator.—The **oil regulator** is shown in detail in Fig. 11, in which (*a*) is a side view and (*b*) a plan view. It consists of a quadrant *a*, a lever *b*, and an adjustable stop arrangement *c* and *d*. The quadrant is bolted to the bracket *e*, which keeps it securely in place. The notches for the adjustment of the regulator lever are made very fine, ten notches to the inch, so as to admit of a very close adjustment of the oil feed-cock. This permits the fire to be closely regulated to the work that the locomotive is performing.

The regulating lever *b* has a latch arrangement, view (*c*), for locking the lever in position on the quadrant that is similar to that of a reverse lever or a throttle. The lever is moved to the extreme right against the solid-steel stop-pin *f* to close the oil feed-cock entirely, and it is moved to the extreme left against the other stop-pin *g* to open the feed-cock wide. Intermediate positions open the feed-cock a corresponding amount.

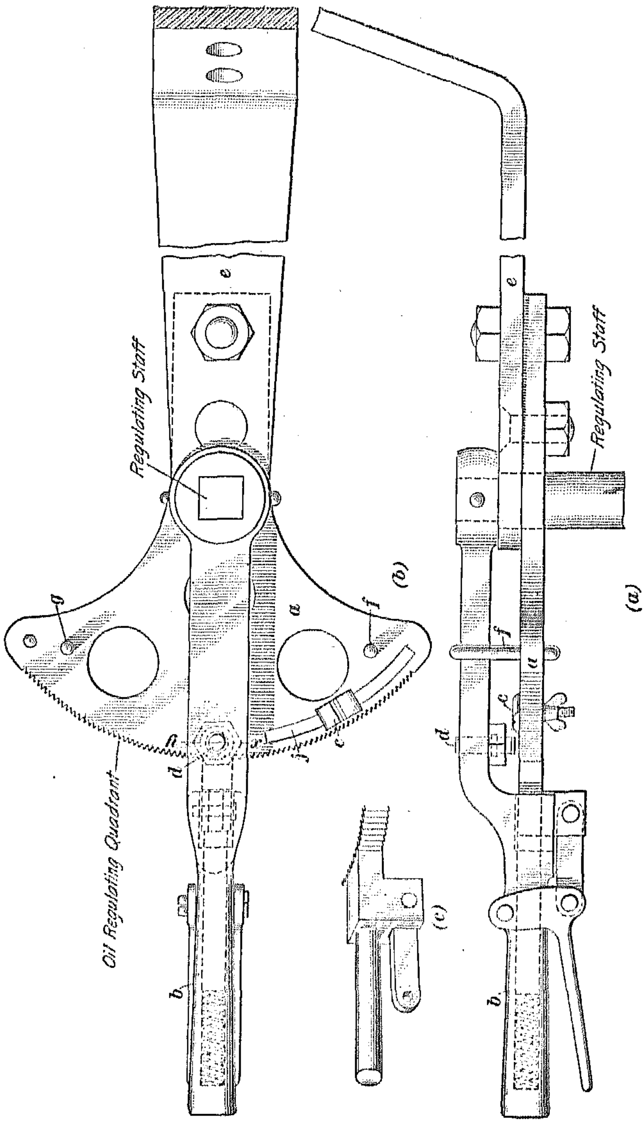

Regulating Staff
Oil Regulating Quadrant
(b)
Regulating Staff
(a)
(c)

FIG. 11

33. The adjustable stop arrangement, Fig. 11, consists of the adjustable stop-bolt *c* in the quadrant, and the stop-pin *d* in the lever. Fig. 12 (*a*) shows a front view and (*b*) a perspec-

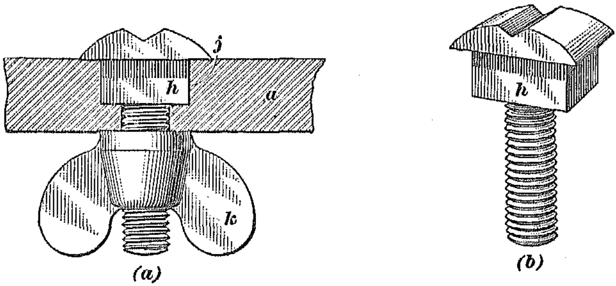


FIG. 12

tive view of the regulating stop-bolt. The stop-bolt *h* travels in the groove *j*, Fig. 11 (*a*), of the quadrant *a*, and the thumb screw *k*, Fig. 12, locks the stop-bolt in the desired position. The lower end of the stop-bolt *h* is riveted sufficiently to prevent the thumb screw from falling off the bolt.

The stop-pin arrangement *d*, Fig. 11, is shown is detail in Fig. 13; the view being a section through the regulating lever *b*, Fig. 11 (*b*), on the line *x y*. Fig. 13 shows that the stop-pin *l* is held against the regu-

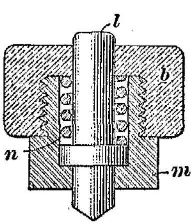


FIG. 13

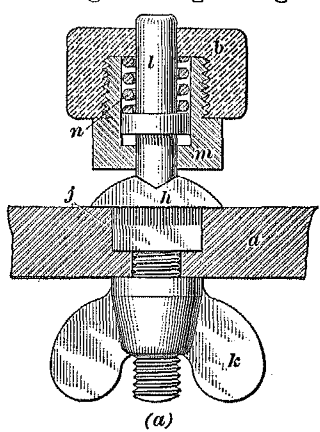


FIG. 14

lating stop-body *m* by the spring *n*, and that the spring acting against the spring-box cap *b* resists the upward movement of the pin.

When in use, the regulating stop is locked on the quadrant in such a position that it will hold the regulating lever open

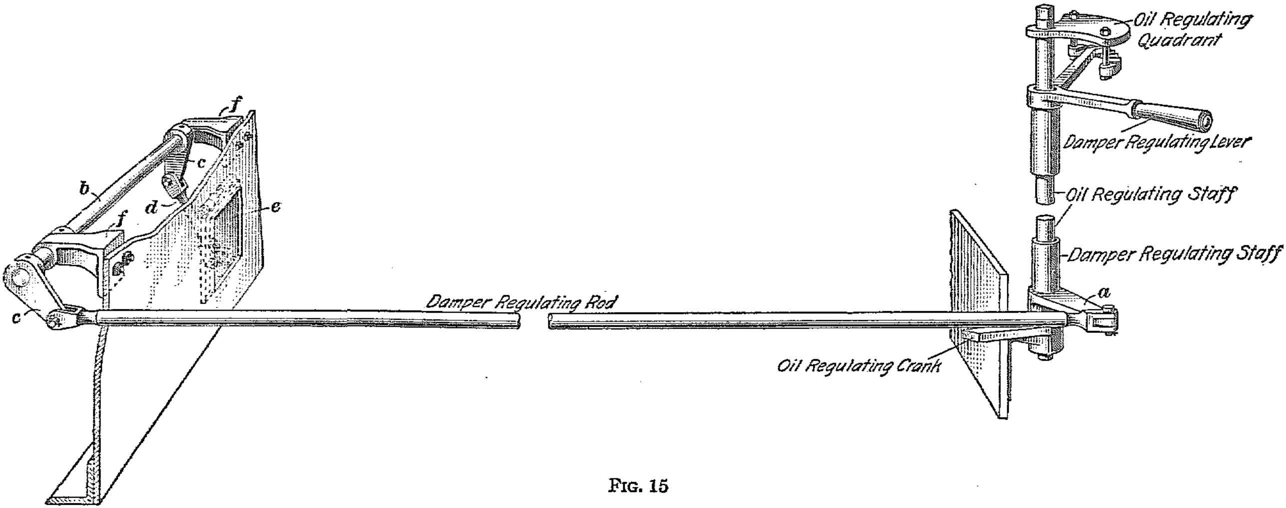

Oil Regulating Quadrant
Damper Regulating Lever
Oil Regulating Staff
Damper Regulating Staff
a
Damper Regulating Rod
Oil Regulating Crank
f
c
b
d
e
f
c

Fig. 15

just far enough to give a "drifting fire"; that is, a fire that is as strong as can be carried while drifting or standing without the pops blowing. When thus locked, the stop-pin registers with the stop-bolt, as shown in Fig. 14.

34. Damper Regulator.—Fig. 7 (*b*) shows that the **damper regulator** is situated in the cab, directly below the oil regulator. The staff for the damper regulator is a $1\frac{1}{4}$-inch pipe, inside of which is the solid-bar staff of the oil regulator; this staff extends below the pipe sufficiently for the oil-regulator crank to be connected to it. The crank for the damper regulator rigging is above the oil-regulator crank and is brazed to the lower end of the $1\frac{1}{4}$-inch pipe staff.

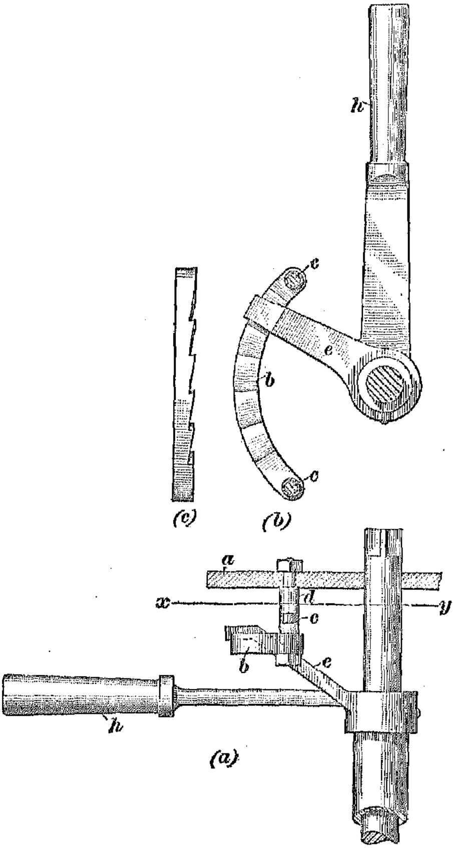


Fig. 16

This is better illustrated in Fig. 15, where the damper pipe staff is broken away to show the oil-regulator staff within. The damper-rigging rod connects to the arm *c* that operates the shaft *b*. The two arms *c* are rigidly fastened to the shaft *b* and the second arm is connected to one end of the rod *d*, the other end of which is fastened to the damper *e*. The shaft *b* is supported by the two cast-iron brackets *f*. Throwing the

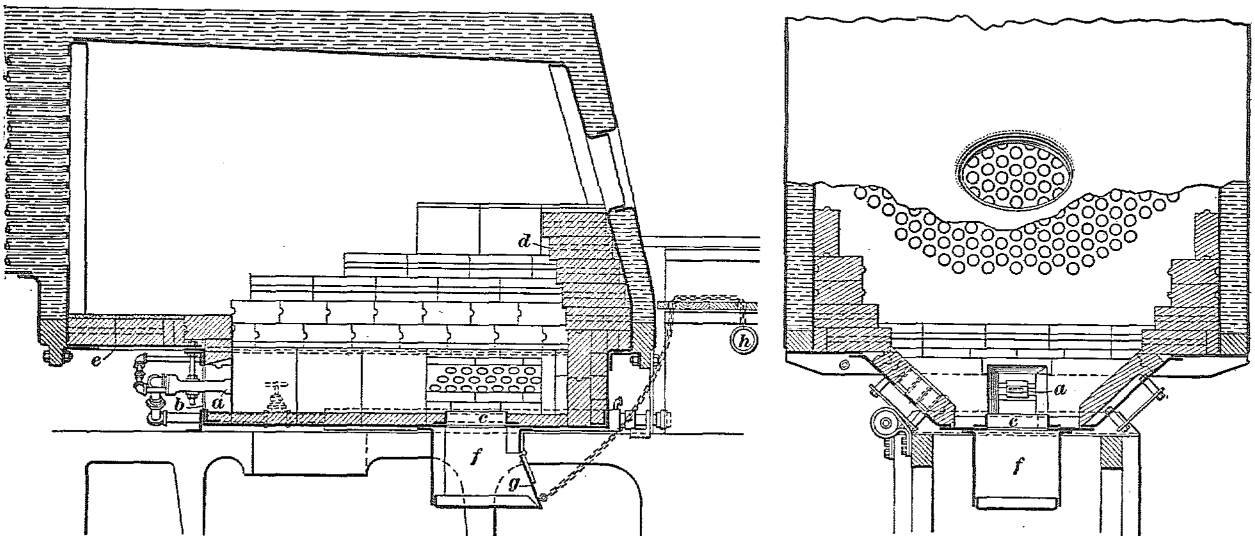
damper-regulator lever, therefore, turns the damper crank *a* and operates the damper-regulating rod, which acts through the arm *a*, shaft *b*, arm *c*, rod *d*, to operate the damper *e*.

35. Details of the damper-regulating lever are shown in Fig. 16, (*a*) being a side view; (*b*), a plan view, as seen below the sectional line *x y*, (*a*); and (*c*), a front view of the quadrant showing the five notches that it contains. View (*a*) shows that the damper quadrant *b* is secured to the oil-regulator quadrant *a* by the bolts *c* and wrought-iron pipe *d*. The handle *h* is connected to and operates the quadrant latch *e*, which engages the quadrant notches to lock the damper regulator in position. The quadrant has only five notches, because that number permits of as close adjustment of the damper as is found necessary.

FIREBOX ARRANGEMENT

36. History of Improvement.—The **firebox** of an oil-burning locomotive differs from that of a coal burner in that coal grates are not used, and the ashpan is replaced by a different form of pan, called the *fire-pan*, that is lined with firebrick. Also, specially arranged dampers and a special form of fire-door are used with the oil burner.

When oil burners were first used in the United States, about 1894, the coal grates were left in place with the idea that in the event of an oil-fire failure, coal could be used. This method of burning oil never was a success, owing to excessive flue trouble due to cold air passing direct from the grates to the flues, and to the fact that the burner was situated at the back end of the firebox. This position of the burner projected the flame forwards, in the direction of the draft, under a brick arch specially prepared for the purpose. The arrangement worked fairly satisfactorily for light loads, but when the engine was working hard, the strong draft created would lift the flame over the arch and the oil spray and gases would enter the flues before being completely burned. This resulted in dense black smoke and a great waste of fuel; besides, it gave excessive trouble from flue leakage.



(a) (b)

FIG. 17

37. To overcome the flue difficulty, the grates were covered with firebrick except for an opening, called a *flash hole*, just in front of the arch through which the air for combustion was admitted into the firebox. This resulted in an improvement both in flue leakage and in combustion and was the practice until 1903, when the burner was placed in the front end of the firebox and the arch and flash hole in the back end. In this position of the burner, the flames were shot backwards over the flash hole under the arch against the action of the exhaust, and they then doubled back again before entering the flues. This arrangement was more satisfactory than any previously tried, but it was still troublesome on account of the smoke produced when the engine was worked hard. To overcome this, various forms of arches were tried without success and finally, in 1904, the arch was discarded.

The next attempt to overcome the smoke produced when the engine was working hard and using a large quantity of oil, was to devise a method of admitting more air to the burning spray in such a way as to mix it intimately with the spray so as to burn the spray completely before it reached the tubes.

This is accomplished by means of a specially designed door that admits air and deflects it downwards at an angle that insures its properly mixing with the oil spray. Thus the smoke problem has been solved, and it has given an impetus to oil burning that has resulted in two systems of single-burner apparatus being extensively used—the *vertical-draft system* and the *horizontal-draft system*.

38. Vertical-Draft System.—An illustration of the fire-pan of a Santa Fe locomotive fitted with the **vertical-draft system** for oil burning is shown in Fig. 17, in which (*a*) is a side sectional view and (*b*) an end sectional view.

The burner *a* is placed in the front end of the fire-pan, in an opening made in the *draft sheet b* for that purpose. This opening is enough larger than the burner to admit sufficient cool air to prevent the burner from overheating; also, the air mixes with the spray as the spray issues from the burner and assists in the ignition and combustion of the oil spray.

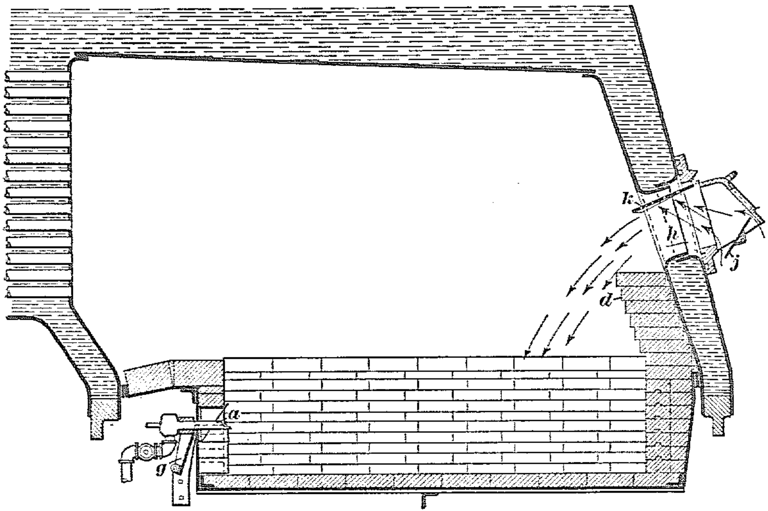
The *flash hole* *c* is placed just forwards of the *flash wall* *d* and the wall is about 5 feet from the burner. Practice has demonstrated that with this arrangement the best results are obtained when the oil spray combines with the air supply at a point about 5 feet from the burner and just in front of the flash wall. With this arrangement, the incoming current of air from the flash hole *c* strikes the horizontal current of oil spray and, thoroughly mixing with it, turns the spray and flames upwards just in front of the extremely hot flash wall *d*, where conditions are best for complete combustion.

In order to locate the burner the proper distance from the flash wall, the draft sheet *b* is employed and the space between the draft sheet and the flue sheet is filled in with an iron plate *e*, which is protected by firebrick, a layer of thin mortar being poured over the brick as shown.

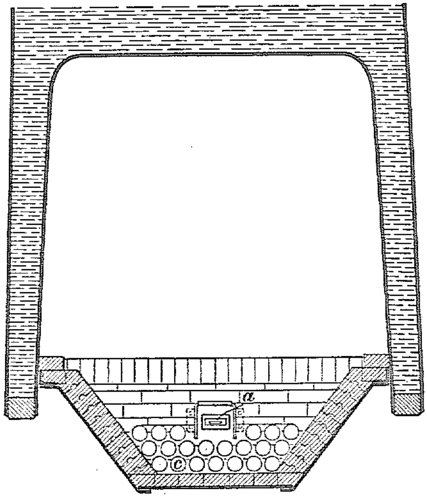
The draft through the flash hole is controlled by means of the sheet-iron draft box *f*, which has a hinged damper *g* on the back side. This damper is regulated by means of the chain *h* that extends up to a point in the cab convenient to the fireman.

39. Horizontal-Draft System.—An illustration of the fire-pan of a Southern Pacific locomotive fitted with the **horizontal-draft system** is shown in Fig. 18, in which (*a*) is a side sectional view and (*b*) an end sectional view. It will be noted that the flash hole, which is in the bottom of the fire-pan of a vertical-draft arrangement, is not used in this arrangement, a series of *draft tubes* *c* being substituted instead. These tubes usually are 3 inches in diameter and 6 inches long, and are expanded into holes in the draft sheet, from which that sheet derives its name. The opening for the burner is made large enough to admit sufficient air to prevent the burner from overheating. In this system, the draft through the draft tubes is regulated by the damper *g*, which is operated by the mechanism described in connection with Figs. 15 and 16.

The burner *a*, Fig. 18, is placed about 6 feet in front of the flash wall *d* as it is found best in practice to have the horizontal draft from the burner and draft tubes meet the downward draft from the fire-door *h* at a point about 5 feet from the end of the



(a)



(b)

FIG. 18

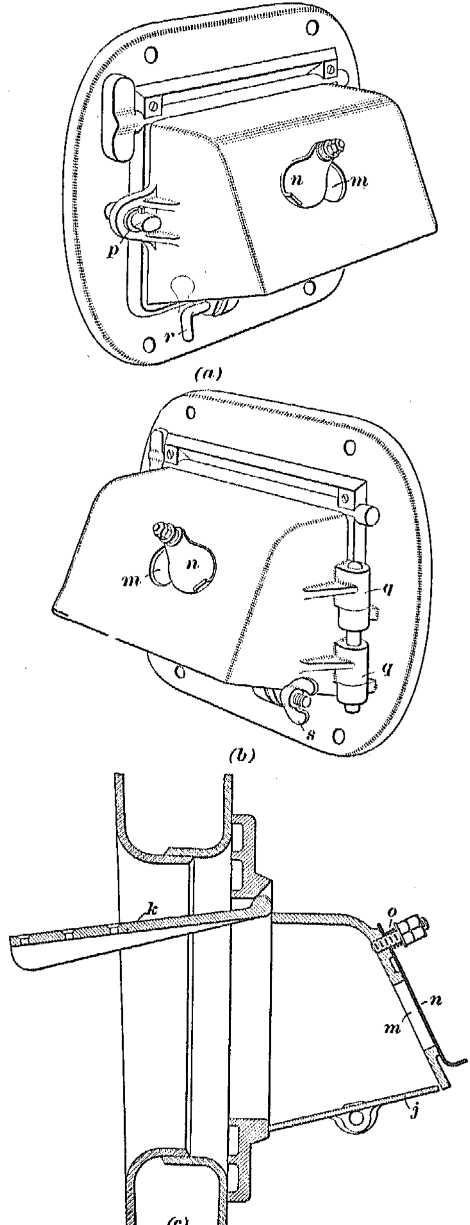


FIG. 18

burner. When the fire-door damper *j* is open, air flows in and is deflected downwards by the deflector *k*, as shown by the arrows. This current of air meets and is thoroughly mixed with the current of air and vaporized oil coming from the burner at a point just in front of the extremely hot flash wall, where conditions are most favorable for combustion.

40. **Fire-Door.**—Details of the **fire-door** shown in Fig. 18 are given in Fig. 19, in which (*a*) and (*b*) are perspective views of the door, and (*c*) a side sectional view. The door is held closed by the lock attachment *p*, view (*a*), and opens to the right on the hinges *q*, shown in view (*b*). The sand hole *m* is closed by the slide cover *n* which is held in any position on

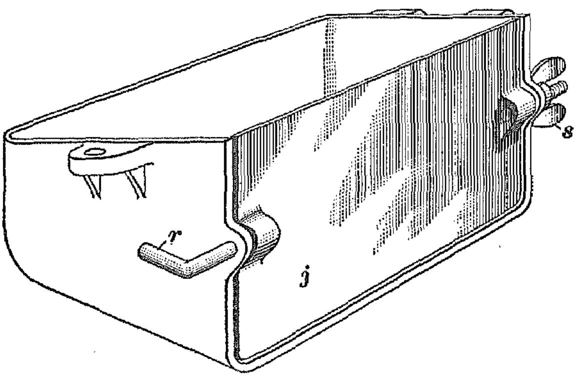


FIG. 20

the door in which it is placed by the tension of the cover spring *o*, view (*c*). The slide is normally closed, as it protects the eyes of the enginemen from the intense glare of the fire and from flarebacks of flame into the cab. However, it may be used as a peep hole to observe the condition of the fire. The deflector *k* is perforated with a number of holes through which sufficient air can pass to prevent injury to the plate from overheating. It is hinged at the upper end and suspended at an angle that deflects the entering air at an angle that properly focuses the point of meeting of the two drafts. The hood of the fire-door is designed to take air at the bottom through the damper *j* so as to protect the enginemen from the glare of the

fire and from a flareback of the flames. Details of the damper are shown in Fig. 20. The damper can be turned to any position desired by the handle *r*, and locked in position by means of the thumbscrew *s*.

41. Fire-Pan.—The **fire-pan** is made of plates $\frac{1}{4}$ to $\frac{5}{16}$ inch thick. It preferably should be secured to the inside sheets of the firebox a sufficient distance above the mud-ring, as in Fig. 18, to permit of calking the mud-ring rivets and joints without having to remove the fire-pan. To insure an air-tight joint, sheet asbestos is used between the pan and the firebox sheets; also, the studs that secure the pan are placed at close intervals, about 12 inches apart.

The extent to which firebrick is used in the fire-pan depends on the form, size, and condition of the pan. The latest practice is to use as few brick as is consistent with good combustion conditions, for additional brick not only adds to the first cost of the equipment, but also adds very materially to the cost of maintenance. It is found that on account of the high temperature in the firebox and of the action of alkali salt and other fluxing agents in the fuel oil, the most refractory firebrick will melt in a comparatively short time. Also, the very severe heat to which the brick arches were subjected and the consequent chilling that occurred every time the fire was cut down to a drifting fire or was entirely extinguished, had the effect of greatly shortening the life of the arch. This belief is substantiated by the Naval Liquid Fuel Report of 1904, which was given after a series of tests covering a period of 28 months. The report advocates dispensing entirely with any brickwork except a lining for a portion of the furnace length and a simple vertical bridge wall whose height could be increased or diminished at comparatively trifling time, trouble, and expense. Experience in locomotive oil burning accords with the Naval Report.

42. The present locomotive practice, Figs. 17 and 18, is to cover the bottom of the pan entirely except where a flash hole is used. The flash wall is built up level with the bottom of the fire-door. The side sheets are covered to a height of two

bricks above the pan, Fig. 18, with the horizontal draft, while with the draft system of Fig. 17 the side-wall bricks slope from the level of the fire-door at the front end to but two bricks above the pan at the draft sheet.

Where too little brickwork is used, the fire has a smoky appearance and soot collects into bunches at various points in the firebox. When this soot is dislodged, it passes through the stack in an incandescent state that is liable to start fires along the right of way. The remedy in a case of this kind is to build up the flash wall and side walls to a greater height until the trouble is overcome. When a patch is put on in the firebox, the brickwork at that point should be built up so as to protect the patch from direct contact with the flames.

TYPES OF BURNERS

43. Von Boden-Ingalls Burner.—The purpose of the *burner*, or *atomizer*, as it is sometimes called, is to separate the oil into a fine spray in order that the oil may readily be converted into a gas by the heat of the firebox and intimately mixed with the air so as to burn completely without forming black smoke.

The **Von Boden-Ingalls burner**, which is the standard burner for the Southern Pacific Railroad, is illustrated in Fig. 21, in which (*a*) is a perspective view; (*b*), a vertical section through the middle of the burner; and (*c*), a view of the end, showing the pipe connections and the positions of the plugs *c*. This burner is known as an *outside mixing burner* because the oil is mixed with and atomized by the steam after they have left the burner. The Von Boden-Ingalls burner is cast in one piece and, like most burners, is of brass, for cast iron is too porous to form a steam-tight partition between the oil and steam chambers. Any leakage of steam into the oil passage causes the oil to feed irregularly.

The burner has two oil supply connections *a*, either of which may be used, the other being closed with a standard plug. The steam connection is made at *b*, the steam pipe leading to the atomizer valve, Fig. 7, (*a*).

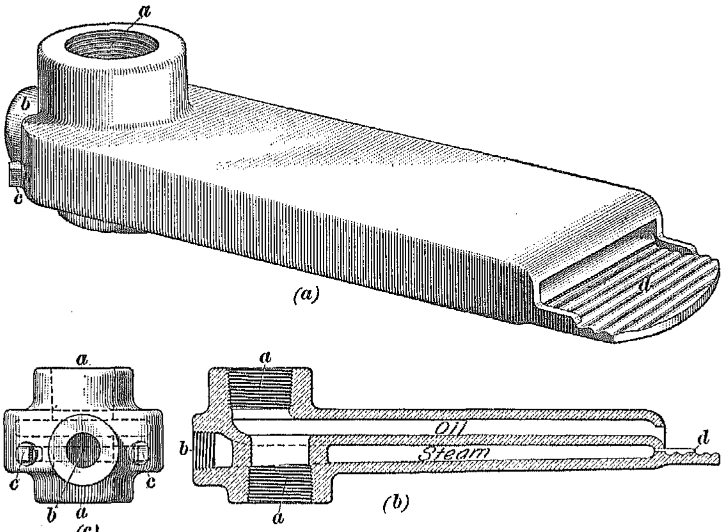


FIG. 21

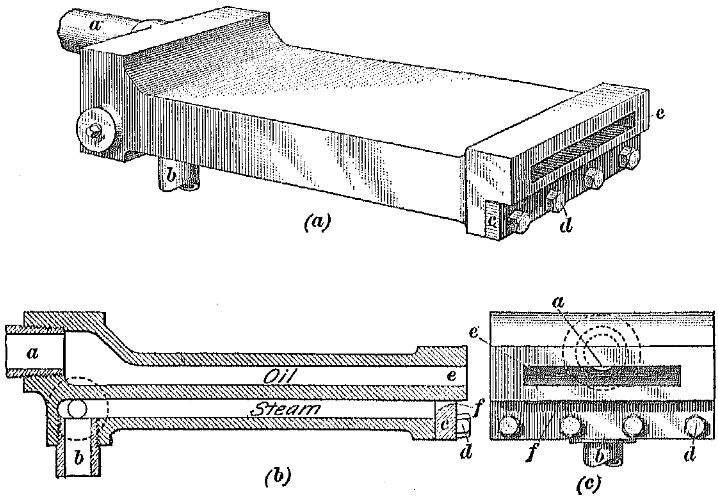


FIG. 22

When the burner is operating, the oil flows through the upper passage on to the corrugated lip *d*, where the steam, issuing from the lower passage, heats it and blows it into fine spray. The purpose of the lip *d* is to assist in atomizing the oil, and, on account of the curved end, view (*a*), to spread the spray so as to make it form a broad flat flame that fills the firebox as completely as possible. The lip, also, retains any oil that may drip from the burner just after the fire is shut off.

44. **Booth Burner.**—An illustration of the **Booth burner**, which has been adopted as standard for the Santa Fe Railroad, is shown in Fig. 22, (*a*) being a perspective view; (*b*), a sectional view through the middle of the burner; and (*c*),

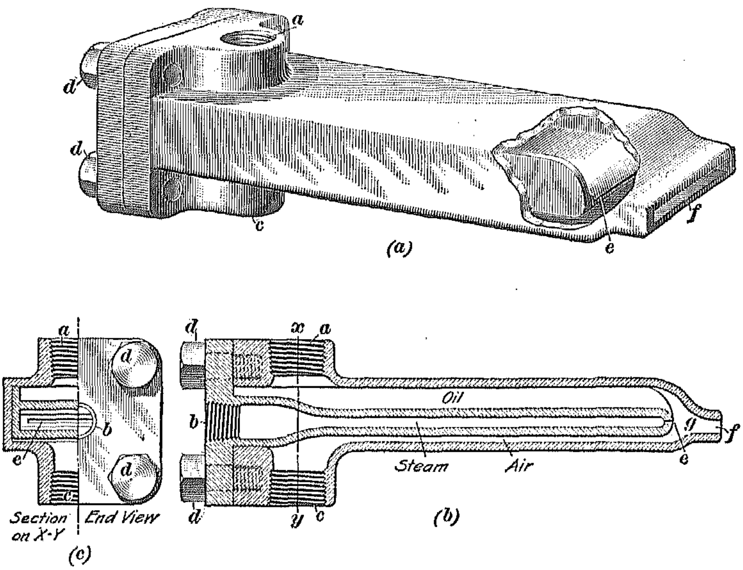


Fig. 23

a view of the discharging end of the burner. This also, is an outside mixing burner, but of a different type than the Von Boden-Ingalls burner. The latter is of the *drooling type* while the Booth burner is known as the *atomizer type*, the steam aperture *f* being set back from the oil outlet *e*, as shown. In the Booth burner, the steam outlet is made adjustable and

renewable by the adjustable block *c*, Fig. 22, which is secured to the body of the burner by the four tap bolts *d*.

The oil connection to the burner is at *a*, and the steam connection at *b*. The oil outlet is at *e*, while the steam outlet is at *f*. In operating, the oil from the upper passage drops down on to the thin jet of escaping steam, which heats the oil and breaks it up into fine spray.

45. Sheedy-Carrick Burner.—The **Sheedy-Carrick burner**, illustrated in Fig. 23, has been used extensively on the Southern Pacific Railroad. It is of the *inside mixing type*, as the oil comes into contact with, and is atomized by, the steam within the burner. View (*a*) shows the burner in perspective with part of the outer wall broken away to show the interior and steam slot *e*. View (*b*) is a vertical section of the burner and shows the steam, air, and oil passages, the steam slot *e*, and the spray delivery orifice *f*. The end view (*c*) shows the pipe connections and the tap bolts *d*. The oil connection is made at *a*, the steam connection at *b*, and the air connection at *c*.

The operation of this burner is as follows: The oil flows by gravity into the chamber *g* in front of the steam jet, being aided in its flow by the ejector action of the steam and spray discharging through the orifice *f*. This ejector action also causes an inflow of air through the passage *c* into chamber *g*, where it mingles with the oil and steam and is discharged with the spray to aid in its combustion.

46. Baldwin Locomotive Works' Burner.—The **Baldwin burner**, Fig. 24, is an outside mixing burner of the drooling type. View (*a*) shows it in perspective, and view (*b*) in vertical section. The view (*c*) of the back end of the burner shows the location of the two cleaner plugs *c* and the bracket bolt holes *d*. View (*d*) shows the adjustable copper steam-orifice plate *f*. The oil connection is made at *a* and the steam connection at *b*. The orifice *i* for the steam chamber is made by the two copper plates *e* and *f*. The plate *e* is held in position by the two bolts *g*, while the plate *f* is held in position by the bolt *h*, but is adjustable on account of the elongated

slot in the plate. In operating, the oil drops from the upper passage on to the jet of steam that is discharged from the

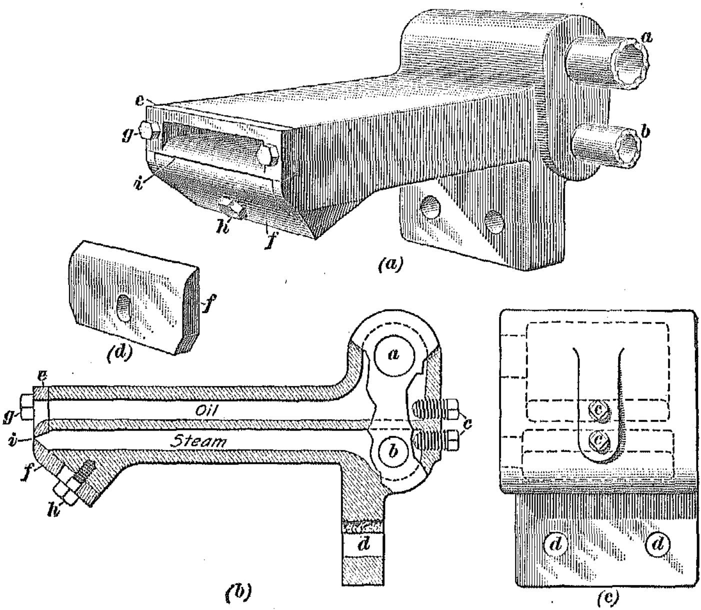


FIG. 24

steam orifice, and the steam atomizes or sprays the oil as in the case of the other burners.

ADJUSTMENT OF BURNERS

47. In all cases, the burner should be firmly secured to either the mud-ring or to the fire-pan in such a way that the vibration or strain on the piping will not throw it out of alinement. Also, the mounting should be adjustable so that the vertical height of the burner above the bottom of the pan can be adjusted as necessary to suit peculiarities of the draft of different engines. It is easier, for slight irregularities of the draft, to adjust the burner to suit the draft conditions than it is to change the draft appliances in the front end.

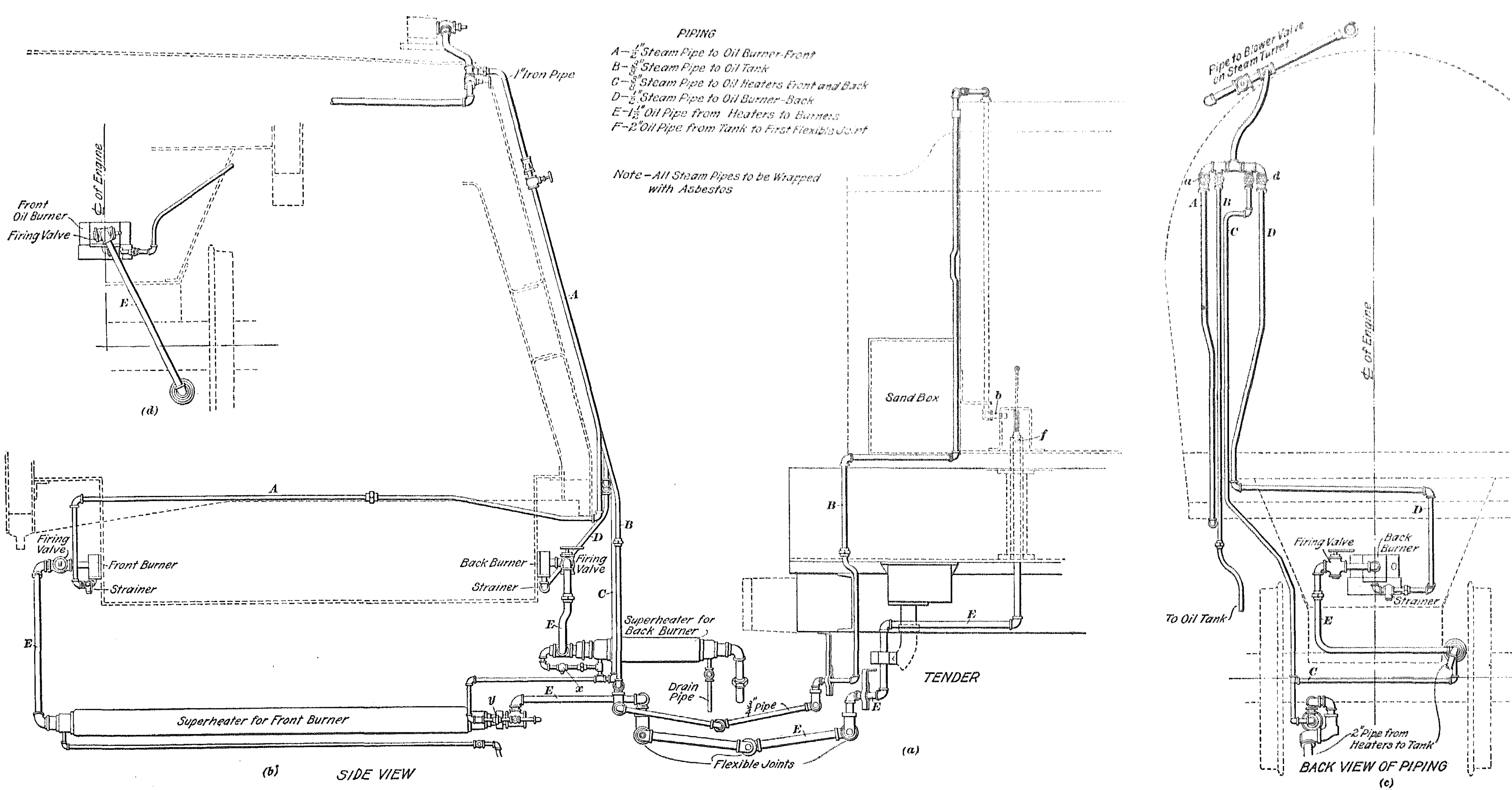
TWO-BURNER SYSTEMS

48. Piping Arrangement.—In Fig. 25 is shown the **Hammel two-burner** arrangement for burning liquid fuel. This arrangement has been adopted as standard by the S. P. L. A. & S. L. R. R. View (*a*) shows the piping arrangement for the oil tank; (*b*), the side view; (*c*), the back-end view; and (*d*), the front-end view of the engine piping. Except that two burners are used, this piping arrangement is practically similar to that of the one-burner arrangement.

In view (*a*), E is the oil feedpipe and f the feed-valve. On account of two burners being used, there are two feedpipes and two feed-valves, one on each side of the tank. The right feed-valve controls the oil outlet to the back burner; the left feed-valve controls the oil outlet to the front burner. The usual practice is to make one of the feed-valve seats extend above the bottom of the tank several inches higher than the other, so that any water that may collect in the oil tank can go into only one oil pipe. Thus, water in the oil tank can extinguish only one burner, the other burner remaining burning and protecting the firebox from sudden contraction. The tank heater pipe B divides at the lower end in the tank into two branches b, one of which goes to the right and the other to the left so as to heat the oil equally for the two burners. The connection between the tender and the engine is made by means of flexible joints, as in the other cases.

49. The superheater for the back burner is on the right side, fastened to the engine frame. On account of its being so close to the oil tank it is only 18 inches long. The superheater for the front burner is on the left side, being fastened to the engine frame below the axles. The pipes E lead from the superheaters to the firing valves, as shown.

In Fig. 25, A is the steam pipe, and a, view (*c*), is the atomizer valve for the front burner; B, the steam pipe to the tank heater; C, the steam pipe that branches as shown in view (*c*) and leads to the two superheaters; D, the steam pipe and d the atomizer valve to the back burner. The oil pipe E leads from



PIPING
A—1/2" Steam Pipe to Oil Burner-Front
B—3/8" Steam Pipe to Oil Tank
C—3/8" Steam Pipe to Oil Heaters Front and Back
D—1/2" Steam Pipe to Oil Burner-Back
E—1 1/2" Oil Pipe from Heaters to Burners
F—2" Oil Pipe from Tank to First Flexible Joint
Note—All Steam Pipes to be Wrapped with Asbestos
1" Iron Pipe
℄ of Engine
Front Oil Burner
Firing Valve
(d)
Front Burner
Strainer
Back Burner
Strainer
Superheater for Back Burner
Drain Pipe
3/4" Pipe
Superheater for Front Burner
Flexible Joints
(b)
SIDE VIEW
Sand Box
TENDER
(a)
Pipe to Blower Valve on Steam Turret
Back Burner
To Oil Tank
2" Pipe from Heaters to Tank
BACK VIEW OF PIPING
(c)

Fig. 25

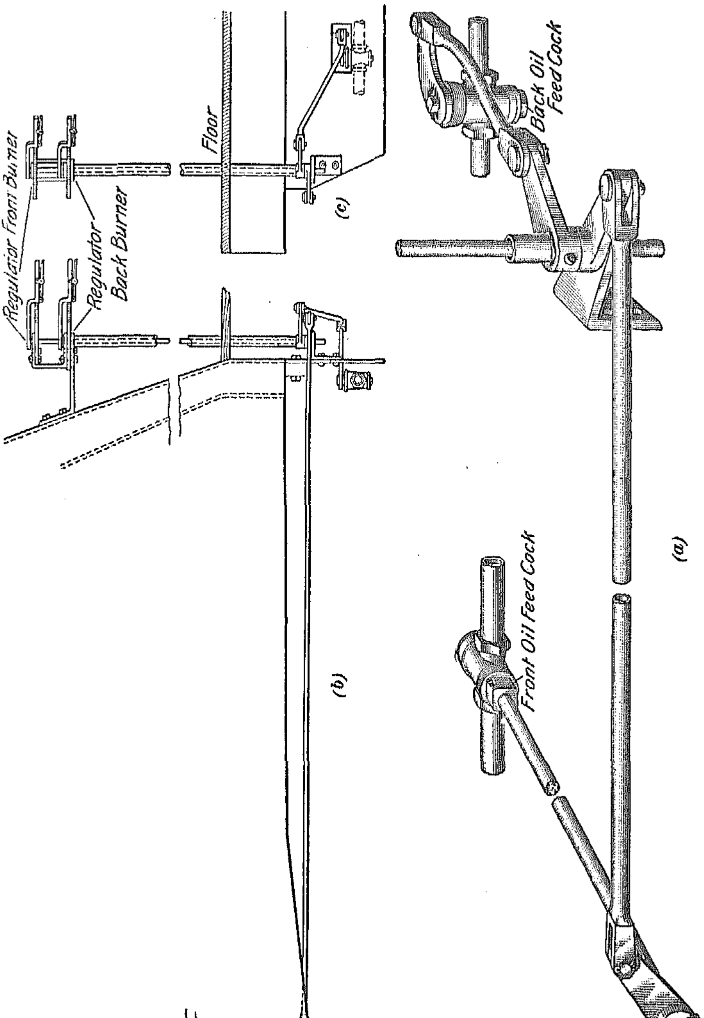
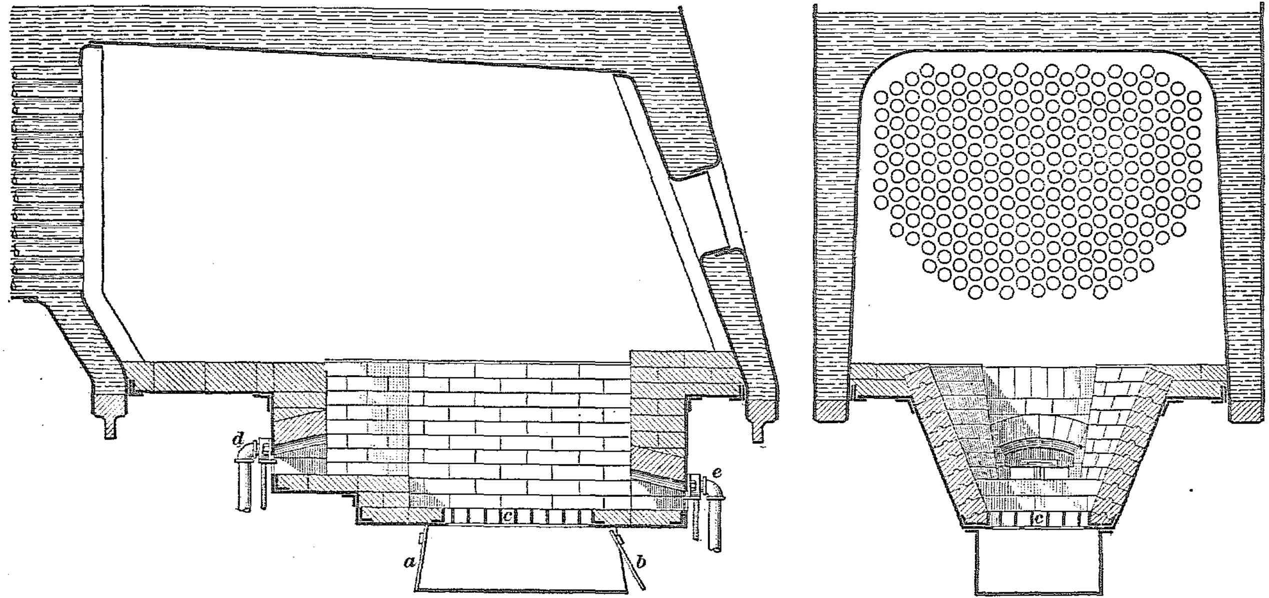

Regulator Front Burner
Regulator Back Burner
Floor
(c)
(b)
Back Oil Feed Cock
Front Oil Feed Cock
(a)

FIG. 26



(a) (b)

FIG. 27

the oil feed-valve in the tank to the burners. As will be noted in view (*c*), there are four pipes *A*, *B*, *C*, and *D*, instead of three pipes as in the single burner; the extra pipe *D* leads to the second burner in this system.

The superheaters are similar in construction to those already described. Each superheater has a drain pipe, as shown, and each is provided with a blow-back arrangement. In view (*b*), *x* is the blow-back cock for the back heater, and *y* the blow-back cock for the front heater. The blow-back arrangement is similar to that already described, both in construction and operation.

50. Oil-Regulating Rigging.—Detail drawings of the oil-regulator rigging are illustrated in Fig. 26. These show that this arrangement for operating the two firing valves is practically similar to the arrangement for operating the firing valve and the dampers shown in Figs. 10 and 15.

In Fig. 26, (*a*) is a perspective view; (*b*), a side view of the rigging; and (*c*), a front view.

51. Fire-Pan Arrangement.—The arrangement of the fire-pan for the Hammel equipment is shown in Fig. 27, in which (*a*) is a side sectional view and (*b*) an end sectional view. The *air grate c* is in the bottom of the pan, as in the vertical draft equipment, only enough air being permitted to enter at the burners to prevent the burners *d* and *e* from overheating.

The dampers are below the air grate, as shown. The usual practice is to keep the front damper *a* closed and to regulate the draft through the back damper *b*.

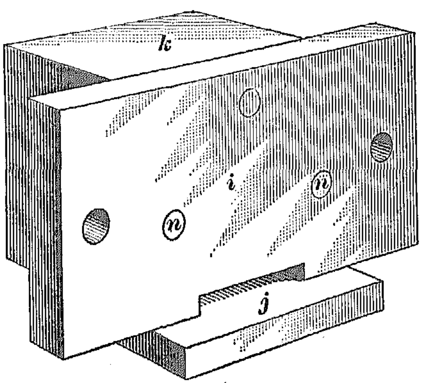


FIG. 28

The front oil regulator and atomizer are opened much more than the back, because the fire from the back burner has to be

thrown backwards in the fire-pan against the action of the exhaust. The usual practice is to carry a medium fire in the back burner and a strong fire in the front burner, so regulating their intensities that the flames from the two burners will meet at about the center of the air grates in the bottom of the pan. This mixes the burning spray thoroughly with the incoming air, which very materially helps the complete combustion of the gases and the elimination of black smoke.

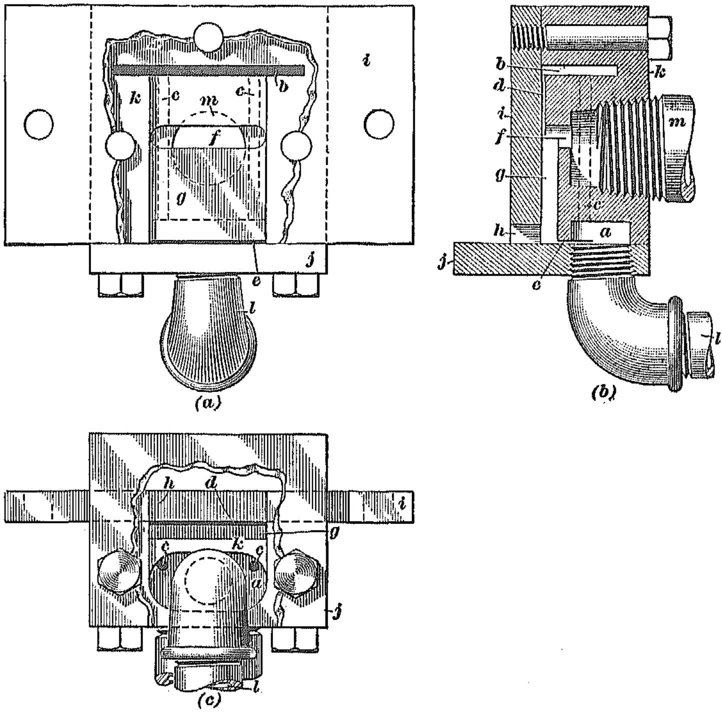


FIG. 29

When the engine is standing, or when drifting with steam shut off, the oil regulator to the back burner is fully closed, but the atomizer for that burner must be left on just sufficient to prevent the burner overheating. The stop or the quadrant of the regulator for the back burner is set for a drifting fire, as in the case of a single-burner equipment. In every

case where one of the two burners is turned off, the atomizer to that burner must be left on a sufficient amount to protect the burner.

52. Hammel Burner.—The burner used with the Hammel equipment is shown in Fig. 28. This burner is made of cast brass in three pieces, *i* being the front plate, *j* the bottom plate, and *k* the body of the valve.

The details of the valve are shown in Fig. 29, (*a*) being a front view with the front plate *i* broken away; (*b*), a side sectional view through the center of the valve; and (*c*), a view of

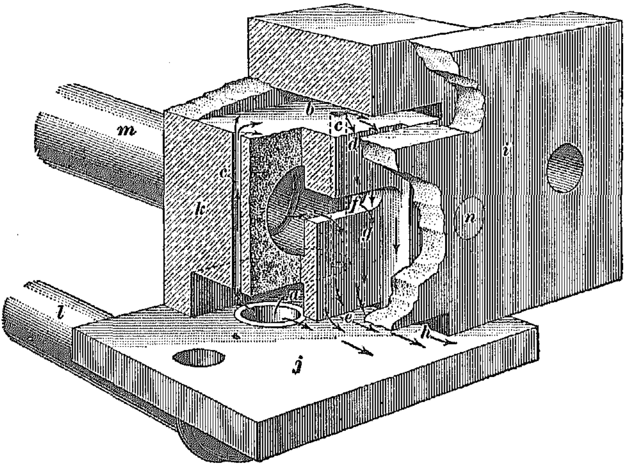


FIG. 30

the valve as seen from the bottom with the bottom plate *j* partly broken away. Fig. 30 shows the valve in perspective with the plate *i* broken away and the body *k* so sectioned as to show the interior construction of the valve. In all cases, *a* is the lower steam chamber; *b*, the upper steam chamber; *c*, the two ports connecting the steam chambers *a* and *b*; *d* the top atomizer port from chamber *b* to chamber *g*; *e*, the bottom atomizer outlet; *f*, the oil inlet to the mixing chamber *g*; *h*, the outlet orifice; *l*, the steam supply pipe; and *m*, the oil supply pipe.

Steam enters chamber *a* and passes through the ports *c* into chamber *b*. The steam from chamber *b*, passing through the

atomizer port *d*, strikes the oil as it issues through port *f* into the mixing chamber *g*. The oil is mixed with the steam and heated in chamber *g* and is then blown down on to the jet of steam issuing from the chamber *a* through the atomizer port *e*, which thoroughly atomizes the oil and throws the spray into the fire-pan through the outlet orifice *h*.

OPERATION OF OIL-BURNING LOCOMOTIVES

53. Roundhouse Inspection.—When an oil-burning locomotive arrives at the roundhouse after completing a trip, it should be thoroughly inspected, so that necessary repairs can be made before the time of leaving on the next trip. The brickwork should be carefully inspected and any loose brick, carbon obstruction, or other obstruction in the fire-pan should be removed. The joints between the fire-pan and the firebox sheets should be inspected and made air-tight. The fire-door baffler should be in good condition and properly adjusted. The burners should not be dripping oil but should be clean and free from obstruction and in the proper position and alinement; the flame from the burner should spread centrally in the firebox. The draft tubes in the burner end of the fire-pan should be thoroughly cleaned out. Any lost motion or vibration in the piping or the parts of the equipment should be remedied. The smokebox should be air-tight, and there should be no leaks in the steam pipes. The petticoat pipe should be properly adjusted and in its right position. The sand used for sanding the flues should be fine, dry sand, thoroughly screened so as to be free of foreign materials that might cause fires. The oil-tank, piping and flexible connections between engine and tender should be tight and free from leaks.

54. Work in Oil Tank.—If a defect is found in the oil tank that necessitates work being done inside the tank, the utmost precaution must be observed before any one enters the tank. A tank that has contained petroleum must never be entered until the tank has been thoroughly washed and steamed out. Petroleum gives off a vapor that will render a person

unconscious and produce suffocation. Also, this vapor is very explosive, so that under no circumstances should a lighted torch, lamp, or lantern or other flame be taken into the tank or near the opening until the tank has been thoroughly cleaned out. When possible, an incandescent electric light should be used for work that is in or around oil tanks, or a light should be reflected on the tank.

To clean out the tank after it has been emptied, fill the tank with water containing several pounds of caustic soda, or *soda ash*, as it is often called; then turn steam on through the tank heater until the water boils over the manhole.

55. Duties Before Departure on Trip.—Before starting on a trip, it should be seen that the oil tanks are full, that the water is drained from them, and that the oil is of the proper temperature. It must also be seen that the tank heater and superheater are in proper order, that the firebox is in good condition, that the fire is burning properly, and that no oil is dropping from the burner or lying in the fire-pan. Care must be taken to see that there are no bricks or other obstruction on the bottom of the fire-pan, because they will have a tendency to drag the fire and cause smoke. Also, it must be seen that a proper supply of the right kind of sand is at hand, for sanding the flues, and that it is dry and well screened.

56. Taking Oil.—It should always be borne in mind that fuel oil gives off a gas that is highly explosive when mixed with the proper amount of air; it must also be remembered that the rate of giving off gas increases with the temperature of the oil. In escaping, this gas fills the surrounding air with an explosive mixture which, if it ignites, will explode and flash back into the tank. For that reason, no flame or naked light should ever be brought nearer than 10 feet of the oil-tank manhole or vent hole. If, in measuring the depth of oil in the tank a light is necessary to read the depth on the rod, either an electric light should be used or the rod should be carried to a light that is at a safe distance from the tank. When filling the tanks, care must be exercised to see that sufficient room is left for the

expansion of the oil when it is heated. The tanks should never be filled to within more than 2 inches of the top.

57. **Temperature of Oil in Tank.**—It is important that the oil in the tank be at the proper temperature. If it is too cold, the oil will not flow as freely to the burner as it should, the fire will lag, and the exhaust will have a greater effect on the fire than it should, due to insufficient oil supply at the burner and to poorer atomization of the oil. Overheating the oil makes it hard to regulate the fire at the burner. The oil gases in the burner and makes the flow of oil to the burner uneven. This causes the fire to fluctuate in intensity, and wastes considerable fuel, because a good portion of the gas from the burner escapes unburned. Also, this condition makes it hard to carry a light fire, as when drifting or standing. The remedy is to shut off the tank heater and superheater and to take cold oil in the tank at the first opportunity. Another bad effect of overheating the oil is that the asphaltum separates from the lighter oils and sinks to the bottom and an increased amount of the lighter oils is driven off as vapor.

58. The temperature to which the oil should be heated depends on its thickness. Oils of ordinary thickness should not be heated much above blood heat, or 98° F. Thick oils, like the Kern River oil, must be heated higher, the very thick oils being heated to 150° F. A good method of judging the temperature of the oil in the tank is to place the back of the hand on the outside of the tank at a level with the top of the oil in the tank.

When possible, the oil in the tank should be heated when the engine is standing. When the heating is done by direct use of steam, the heater valve should be opened up strong and left on until the oil is of the right temperature. It should then be entirely shut off and not used again until necessary. It is bad practice to leave the heater on continuously a small amount. If there is a heater coil in the tank, the heater valve must be opened just sufficient to produce steam or water at the drain cock under the tank and keep it on continuously when the weather demands it.

59. Use of Superheater.—When the weather necessitates the use of the superheater, the heater should be used continuously and the drain cock should be wide open to take care of the water of condensation. The superheater valve, Fig. 7, should be opened only a slight amount so as to give but a light flow of steam through the superheater. If the valve is opened too wide, the high steam pressure in the superheater will overheat the oil and cause an intermittent flow to the burner.

60. Starting the Fire.—To start a fire in a cold engine where there is an external source of steam to operate the oil-burning apparatus and the blower:

1. Drain the oil tank and heat the oil in the tanks to the proper temperature. See that the firebox and fire-pan are in good condition and that oil has not accumulated in the fire-pan, as it might cause an explosion. Open the atomizer valve sufficiently to blow all water out of the burner and to heat the burner.

2. Close the atomizer; then open it just a small amount and put the blower on lightly. Place a lighted piece of oil-soaked waste in front of the burner, close the fire-door and fasten it. Gradually open the regulating valve a sufficient amount to start the oil burning.

3. After the spray from the burner has ignited, regulate the oil supply, the atomizer, and the damper, so as to give a very light fire, without black smoke, until the water in the boiler is warmed, when the fire can gradually be increased. A too heavy fire while the water and flues are cold is very injurious to the boiler and staybolts. As the fire is very liable to go out during the time the firebox and boiler are warming up, a close watch should be kept on it until the engine has become hot.

It is important that this order of procedure be followed, because if the waste is put in before the water is blown out of the atomizer, the waste fire may be put out and the oil will escape into the fire-pan. If the oil-regulating valve is turned on before the atomizer, or is opened too wide, too much oil may be thrown into the firebox and there will be an explosion that is liable to burn the man starting the fire. On this account,

great caution must be exercised to avoid explosions when lighting fires. A person should always stand to one side of the fire-door when starting a fire, so as to escape injury if an explosion should occur.

61. To start the fire where there is no outside source of steam supply to operate the burner and the blower, it will be necessary to use wood until sufficient steam is generated to operate the atomizer and blower. This will require at least 10 pounds of steam. Before starting the fire with wood, the burner must be protected by firebrick to avoid injury from overheating. In firing with wood, care must be exercised not to damage the brickwork. Also, all wood embers and other material that might cause fires along the right of way must be removed from the fire-pan before the engine leaves the terminal.

To start the oil burning, blow out the burner and use a piece of lighted oily waste as before. Start the atomizer and blower medium hard, and fasten the fire-door shut. Turn the oil on very gradually, and when it ignites reduce the atomizer and blower to a light fire, adjust the damper, and close the oil regulator gradually until the stack becomes almost clear. To start a fire in a white-hot firebox, no waste need be used.

62. **Use of Atomizer.**—The atomizer has two functions to perform: It must atomize the oil to a fine spray, and must project the burning spray into the firebox with sufficient force and in such a manner as to fill the entire firebox with flame, against the action of the exhaust. As the action of the exhaust tends to prevent the flames from traveling to the back end of the firebox, the harder the exhaust, the greater must be the force of the atomizer. Also, as the exhaust becomes lighter, the atomizer must be eased up. The atomizer is used at its lightest when the fire is cut down to a drifting fire, but at no time must it be cut down so low as to permit oil to drip from the burner. Too much atomizer causes steam to lag and the engine will drum and smoke.

63. **Use of Oil Regulator.**—In a coal-burning engine, the amount of coal fired varies with the work that the engine

is doing. Likewise, the quantity of oil burned with an oil burner must vary with the rate of work that is being done. When the engine is exerting a light pull at slow speed, the oil regulator should be cut down fine; as the speed or the pull increases, the regulator should be opened a corresponding amount. Opening the regulator wider increases the quantity of oil burned, and partly closing it reduces the oil burned.

The engineman and fireman must work in harmony. Before changing the position of the throttle or reverse lever, the engineer should first notify the fireman so that the oil-regulating lever and the throttle can be opened or closed simultaneously. The regulator must be opened wide enough to have the firebox full of flame by the time the first exhaust occurs, otherwise leaky flues are apt to result. The throttle should be opened gradually; also, the atomizer and regulator should be opened gradually, and in about the same proportion, the damper being opened the proper amount. If the reverse lever is dropped a few notches, the regulator and atomizer should be opened a little. If the reverse lever is hooked up, the regulator and atomizer should be closed a proper amount. As the throttle is closed, the regulator, with one swing, is brought back to the adjustable stop on the quadrant, and the atomizer is brought back to its corresponding position. This stop is so placed on the quadrant that when the regulating pin is in position the fire will be as heavy as can be carried while the engine is standing or drifting. In drifting, the regulator is against the stop and the damper is closed to protect the flues.

In all cases, the atomizer must be opened first, the oil regulator second, and the damper last. On closing, the oil regulator is always closed first, the atomizer second, and the damper last. When the regulator is in position for the work the engine is doing, the atomizer should be opened gradually until the stack just clears up the smoke to a faint haze. The regulator should be changed in accordance with changes in the steam pressure, but the temperature of the firebox should always be changed gradually, both to and from the working temperature. The aim should be to maintain the firebox temperature as nearly uniform as possible throughout the trip.

64. Use of Dampers.—The proper manipulation of the dampers is very essential to the successful operation of an oil burner and to the economical use of the oil. From the standpoint of economy, just enough oil to do the work should be burned; and to accomplish this, just enough steam to atomize the oil and just enough air to burn it must be used. Any more than just enough of either air or steam will increase the amount of oil burned. The loss of heat due to excess air increases rapidly with the amount of air used in excess, and it is the source of a large loss in the heat efficiency of the boiler when proper use is not made of the dampers.

When two dampers are used, the front one is usually kept closed while the admission of air is regulated by means of the back damper. The amount that the damper should be open depends on the work of the engine. When working hard, the damper is wide open, and it is closed in proportion as the work is reduced. The damper should always be closed whenever steam is shut off, as on descending grades, while standing, or while drifting into stations, so as to prevent cooling off the firebox as much as possible. The damper should be opened by degrees as the oil regulator is opened.

65. Forcing the Fire.—With oil, it is possible to maintain full steam pressure practically up to the total power of the locomotive. However, as the amount of oil burned, and therefore the temperature of the firebox, increases with the power exerted, it is possible, when forcing the engine, to obtain firebox temperatures that are much higher than those obtained in coal-burning engines. This high temperature is very destructive to the firebox and flues and it develops leaks and wastes fuel. Prolonged forced firing may melt the rivets off the inside of the firebox and overheat the plates. Therefore, forced firing is to be avoided whenever possible.

66. Using the Injectors.—As a general rule, the injectors should not be used except while the engine is working steam. If it becomes necessary to use the injector when standing or when drifting, a heavier fire must be carried and the blower put on lightly to clear up the stack. When possible, in starting

the train, the injector should not be put on until the train has attained speed and the firebox has assumed working temperature. The injector should be worked continuously while steam is being used, but should be shut off before the throttle is closed, so as to avoid leaky flues. The feed of the injector should be adjusted to the work of the engine. In approaching a point where the train is to tip over a hill, or where it is to make a stop, the height of the water should gradually be raised, so as to protect the crown sheet when the engine tips over the hill, or while standing. The injector should be shut off just before the throttle is closed in tipping over the hill. Two injectors should never be used if one will do. Where two are necessary, one should be left on full and the feed regulated with the other.

67. Smoke.—In firing an oil burner, it is very important to keep close watch of the stack for black smoke. With proper manipulation of oil, atomizer, and dampers, there should be no black smoke at any time, if the apparatus is in good order, except while sanding the flues. Black smoke, therefore, indicates either improper firing or trouble with the apparatus. Assuming the apparatus to be in working order, then black smoke might indicate too much oil, steam, or air. The draft produced by the exhaust depends on how hard the engine is working. If more oil is used than is suitable for the draft, black smoke will result; this can be avoided by cutting down the oil supply. If the dampers are open too much or not enough, or if the atomizer is on too strong, smoke will be caused.

Black smoke is to be avoided because it covers the flues with soot, which prevents the heat of the fire from being absorbed by the water of the boiler. Soot will make a steam failure quicker than anything else. When soot begins to deposit on the flues, the steam begins to lag, which requires more oil to be used to maintain steam pressure; the more oil used, the more soot is deposited and the more the steam lags, so that a steam failure will quickly result if the flues are not sanded.

Shutting off, or hooking up the reverse lever before the oil regulator is operated to regulate the oil supply, will cause smoke. The fireman must pay close attention and regulate

the fire in strict accordance with the changes in the draft produced by the exhaust.

A fallen brick, a lump of carbon on the bottom bricks, or an improperly adjusted burner may distort the path of the flame and cause it to drag and produce black smoke.

68. The color of the smoke differs for different reasons. Deep black smoke indicates either that the combustion conditions are very faulty, or that there is something wrong with the apparatus. For best results, the oil regulator should be so set as to just maintain steam pressure, and the atomizer should then be opened gradually until the smoke clears up to a gray haze color. It should not be opened far enough to clear the stack completely, as to do this will burn more oil than when the other method is used. If too much oil is used either for the

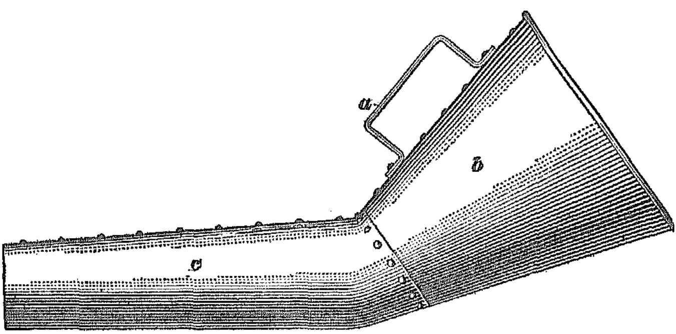


FIG. 31

draft or for the atomizer, it will be indicated by black smoke, and the amount of black smoke will indicate to what degree the oil is being wasted. Forced firing will cause smoke and rapidly fill the tubes with soot.

If the smoke is of a bluish-white, milky color, it indicates that the fire has gone out and that the oil is running out into the fire-pan. This will be indicated also, by the odor. If black smoke issues intermittently, it indicates that the oil is being supplied to the burner unevenly or intermittently.

69. Sanding the Flues.—After an engine has been smoked, it must be sanded to clear the soot from the tubes.

To sand the flues thoroughly, a sand funnel, Fig. 31, is used. The funnel is handled by means of the handle *a*, the funnel *b* being filled with sand and the spout *c* inserted through the sand hole *m*, Fig. 19. The exhaust draws the sand out of the funnel and through the tubes in such a way as to scour the soot free. The soot is carried out in the form of a black cloud. The spout of the funnel should be so moved during sanding that the sand will be drawn through all the flues, as otherwise the side flues would very probably not be sanded. Also, sanding should be continued as long as quantities of black smoke follow the act of sanding. On the other hand, only enough sand for the purpose should be used. When only a light sanding is required, a scoop, like that shown in Fig. 32, is used; in many cases, this scoop is the only sander used.

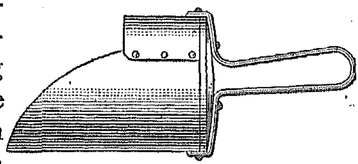


FIG. 32

70. Sanding should be done when the engine is working hard and the exhaust is strong. If the exhaust is not sufficient, the engineer should drop the reverse lever and open the throttle sufficiently for the purpose. Closing the damper will aid very materially in sanding.

The engine should be well sanded, where practicable, on the way from the roundhouse to the train, as the flues are smoked up in starting the fire and while standing around the terminal. When sanding the tubes while on the road, care must be taken to choose a spot where burning soot that may be thrown from the stack will not start a fire along the right of way. Engines should not be sanded under signal bridges or at places where soot will light on buildings.

The engine should be sanded soon after leaving the terminal and as often thereafter as the engine has been smoked. If the stack is kept clear, an occasional light sanding, say every 50 miles, will be sufficient. When the engine is smoking on account of defects, it must be sanded as frequently as necessary.

71. Use of Blower.—The blower should never be used unless absolutely necessary, because its misuse is the cause of much flue trouble. The blower should never be operated when the fire is extinguished. It should never be used stronger than just sufficient to clear the stack of black smoke, because a stronger draft than is necessary only absorbs and carries away heat and cools, instead of heating, the firebox. If the fire is a light one, it very probably will cause the flues to leak.

As the steam pressure increases, the action of both the blower and the atomizer will increase; therefore, the oil supply must be increased proportionately or else the blower and atomizer must be cut down. When the fire is extinguished, the blower must immediately be shut off and the dampers closed to prevent sudden cooling of the firebox tubes.

72. Shutting off the Fire.—To put out the fire, close the oil feed-valve on the tank and wait until all the oil that is in the pipe between the feed-valve and the burner is burned out. Then blow out of the tubes and burner all the oil possible and close the oil regulator; then close the atomizer and then the dampers. Care must be taken that the tank drain valve is closed. When a stack cover is used, the cover should be put on so that the engine will cool as slowly as possible in order to protect the tubes.

73. Slipping of Engine.—If the engine firebox is heated, the fire should always be started before the engine is moved, so as to prevent cool air from being drawn through the flues and thus cause the flues to leak. It is very hard on the flues for the engine to slip and every precaution must be taken to prevent slipping. Should slipping occur, the fireman must swing the oil regulator open, so as to give a good strong fire during slipping, moving the regulator back again to the proper position when slipping ceases.

74. Drumming.—The drumming of an engine is very annoying, especially on passenger trains and at stations; the utmost care should, therefore, be exercised to prevent it. Drumming may be due to faulty brickwork in the fire-pan, to

too much oil when the engine is working slowly, to too much atomizer, or to the dampers being opened too far.

75. Handling Equipment on the Road.—Whether or not an engine crew will be successful in handling an oil-burning locomotive will depend on the care taken of the firebox and tubes. The care of these parts is of more importance than making the time. If by any chance the tubes are made to leak badly, it will be impossible to make the time, and they will be very troublesome. Therefore, every precaution must be taken to avoid leaky tubes and black smoke. Fluctuations in steam pressure must be avoided, but when the pressure does fluctuate it must be brought back to normal gradually.

When starting, care must be taken, if possible, to prevent the engine from slipping. The engineer should notify the fireman when he is ready to open the throttle, so that the regulating valve can be gradually opened at the same time. The regulating valve should be opened sufficiently to make sure that the exhaust will not put out the fire nor yet make heavy black smoke. The atomizer and the oil should be gradually increased as the speed increases, enough oil being used just to keep on the verge of black smoke until the firebox becomes thoroughly heated. As the reverse lever is hooked up, the oil regulator, atomizer, and damper must be adjusted accordingly. The fire must not be forced more than is absolutely necessary, because that practice leads to trouble; it is better to accelerate the train more gradually than to force the fire unduly.

After the firebox has become hot, the injector may be put on and the flues sanded thoroughly to get them in the best condition for the run. During the run, the fireman should watch the steam gauge, the stack, and the appearance of the fire for indications as to how the oil is being burned. With proper attention, the steam pressure need not change over 2 or 3 pounds, and a greater drop than this should be avoided on account of the bad effect it has on the flues. If, at any time, the engine is smoked, it should be sanded as soon after as circumstances will permit. Too frequent sanding, however, is to be avoided.

76. When going into a station where a stop is to be made, care must be exercised not to cut the oil supply so low before the throttle is closed that the exhaust will put out the fire. With the fire out, three or four exhausts of cold air through the tubes will set them to leaking. When the throttle is closed, the regulator should be brought to the stop, the atomizer cut down so that it will just keep oil from dripping into the pan, and the damper closed to the proper opening. The atomizer must not be entirely shut off. The injector should be shut off just before the throttle is closed.

When approaching a point where the train is to tip over a grade, the height of the water must be regulated so that both injectors can be shut off just before the throttle is closed. On the down grade, the oil regulator is brought against the stop, and the atomizer cut down to the proper amount for the oil being used. During times that the injector must be used while the engine is standing or drifting, a suitable fire must be maintained for the protection of the flues.

77. Leaving Engine Alone.—If the engine is to be left alone by the crew, the fire must first be put out, the dampers closed, and the oil feed-valve in the tank closed. Also, covering the stack will aid very materially in keeping the firebox hot and reducing the contraction of the flues and the sheets. When starting the fire, if the brickwork is hot enough, it will not be necessary to use lighted waste. The drip valve to the drain cock should be closed.

78. Putting Engine in Roundhouse.—When putting the engine in the roundhouse, put out the fire by closing the tank oil feed-valve and let the oil in the pipe burn out. Then blow the burner thoroughly and close the oil regulator so that no oil can leak into the burner and fill and stop up the burner with carbon. The stack cover should be put on and the drip valve to the drain valve closed.

OIL-BURNER TROUBLES

79. Precautions Against Fires.—The netting and, in most cases, the deflector plate are removed from the front end of an oil burner so that the exhaust will throw from the firebox any loose burning material which may set fire to property near the track. For this reason no waste, or other inflammable material should be thrown into the firebox, or left on the deck of the engine where it will be carried into the firebox through the fire-door. Material used for starting the fire, if not removed, will be thrown out from the stack and is liable to cause fires. Under certain conditions of combustion, soot will form in quantities in the firebox and eventually will be thrown from the stack in an ignited condition that is liable to cause fires. When the engineer observes sparks being thrown from the stack, he should report at first opportunity, by wire, to the superintendent and to the master mechanic and should report the trouble on the work book at the end of the trip.

Fires are sometimes started from sparks caused by inflammable material in the sand used for sanding the flues. Care should be observed to see that there are no bits of charcoal, wood, waste or other inflammable matter in the sand. Where the sand is found to contain material of this kind, the engineman should report the fact by wire at the first opportunity.

80. Obstructions in Fire-Pan.—A fallen brick, a bank of charcoal, or any other obstruction in the fire-pan that obstructs the path of the flames will cause the engine to smoke badly and the steam to lag. Any such obstruction should be removed before the engine starts on the trip. If it occurs during the run, it should be removed at the first opportunity. The best time to do this is while the fire is cut down to a drifting fire at a station. If the obstruction is a fallen brick or something that can be moved, it can be shoved to the forward end of the fire-pan out of the way until an opportunity occurs for removing it. A fallen brick or other obstruction in the fire-pan is indicated by the engine smoking, and by the fire flashing back into the cab, filling the cab with smoke and gas.

81. Fire Drags on Bottom Brick.—If the bottom of the fire-pan is rough and humpy, or if the burner is too low or improperly adjusted, the fire will drag on the bottom brickwork. This will cause black smoke, the steam will lag, and coke will form on the bottom bricks where the oil spray strikes the brick. The cause of this trouble should be located and remedied at the first opportunity.

82. Insufficient Oil to Burner.—If oil does not flow to the burner as freely as it should, it will be indicated by the steam lagging and by the fact that opening the oil regulator wide does not have any forcing effect on the fire. Also, the exhaust will have a much greater effect on the fire than it should.

The trouble may be due to the tank feed-valve being obstructed, the oil being too cold, or a partial stoppage of the oil pipe or the burner.

To remedy this fault, first see whether the tank valves are wide open; then note whether the oil is of the proper temperature. If it is, use the blow-back cock and blow out the burner and the feed-valve oil pipe to remove any obstruction.

83. Obstruction in Burner.—The burner may be clogged up with sand, waste, or other foreign matter introduced through the oil tank, or, oil may have leaked into the burner at a time when the atomizer was shut off and the burner was hot. This would cause the oil to carbonize or coke and thus clog the burner. First, try to blow out the obstruction with steam from the blow-back arrangement; if this cannot be done, the burner will have to be removed and cleaned out.

To blow out the burner, close the tank valve, open the regulating valve full, close the drain cock on the superheater, open the blow-back cock full, open the superheater valve in the cab *until the oil is burned out* of the oil pipe, and then open it up full and leave it open for a time, or until the obstruction is blown out of the burner. Then close the superheater valve, the regulator valve, and the blow-back cock. If the obstruction cannot be blown out, the burner must be cleaned out.

84. Obstruction in Oil Feed-Valve.—An obstruction in the oil feed-valve will be due to a partial clogging of the oil

feedpipe or the tank valve, and should be blown out as follows: Close the oil-regulating valve and the superheater drain cock. Open the oil feed-valve on the tank and then the blow-back cock. Next, open the superheater valve sufficiently to blow the obstruction back into the oil tank.

85. Irregular Flow of Oil to Burner.—If the flow of oil to the burner is irregular, it will be indicated by the sound and appearance of the fire, which will fluctuate with the flow of the oil, and occasionally by puffs of smoke at the stack. If the flow is intermittent, smoke will be ejected irregularly from the stack and a series of explosions will occur in the firebox.

An intermittent flow may be due to the blow-back cock being partly open or leaking, to water in the oil pipe, to the oil being too hot, or to a leak in the partition of the burner that separates the oil and the steam chambers. If fully closing the blow-back valve does not stop the trouble, close the superheater valve tight and open the superheater drain cock wide. This will stop the trouble if it is due to a leaky blow-back valve.

If the trouble is due to water, drain the tank, and, if it can be done at the time, apply the tank heater strong enough to mix the remaining water thoroughly with the oil. The water enters the pipe in a slug that momentarily puts out the fire when it enters the burner, as it cuts off the supply of oil momentarily. It is the fire going out and relighting that causes the sounds of explosions.

If the oil is too hot, shut off the superheater, and the tank heater, too, if necessary. The superheater may have been on too hard. If the oil in the tank is too hot, take cold oil at the first opportunity. Very probably the superheater is causing some of the lighter oils to vaporize and the vapor acts similarly to the water slug. A leak in the partition of the burner will admit steam into the oil chamber that will act like the gas or like a water slug.

86. Fire Goes Out.—Great care should be exercised at all times to avoid letting the fire go out, especially when the engine is moving or when the blower is on, for leaky flues are quite sure to result. That the fire has gone out will be indi-

cated by the odor and by a bluish-white milky smoke at the stack.

Before starting the fire in a hot engine that has been extinguished, be sure to put the blower on strong enough to draw the gases from the firebox, as otherwise an explosion of the gases may occur. When attempting to light the fire, keep to one side of the fire-door to avoid possible injury.

87. **Leaky Flues.**—Leaky flues are the one thing that both the engineman and fireman must exert continual vigilance to prevent. If the tubes are kept from leaking, everything will go along smoothly; once they start to leak, it will be a constant fight to prevent a steam failure. If the flues start to leak the engine should be worked as hard as possible, so that the fire can be forced in the hope that the leaky flues will take up. To shut off steam at this time will mean more flues leaking. The plan is to force the fire so as to raise the firebox temperature and cause the leaks to take up. If necessary, the brakes may be applied sufficiently for the purpose of increasing the pull. If it becomes necessary to shut off, keep the firing valve open as far as possible and use the blower lightly while drifting.

In the two-burner equipment, the leaks tend to drown out the forward burner; therefore, the back burner should be crowded with the view of throwing the flames back as far as possible toward the flue sheet.

88. **Overheated Crown Sheet.**—On account of the very hot fire in the firebox of an oil-burning engine, the crown sheet, if uncovered, will burn in a much shorter time than it will in a coal-burning engine. On the other hand, the crown sheet of an oil-burner is most apt to burn while working steam, since the fire is cut down low at other times. When the throttle is open and the engine is working steam, the height of the water is raised, If, therefore, the water is worked down low while using steam, closing the throttle will only make conditions worse.

If the crown sheet is found bright hot, cut the fire down low instantly, but keep the throttle open—do not touch the reverse lever—and keep on running until the sheet cools. Examine

the crown sheet carefully before proceeding, and if deemed necessary cut down the working steam pressure to what is considered safe to bring in the train.

89. Tank-Heater Pipe or Hose Bursts.—Should the tank-heater pipe or hose burst, the tank heater will be put out of commission. It may then be necessary to heat the oil through the blow-back valve, as follows: While the engine is standing, close the dampers tight and put out the fire, as the regulating valve must be closed tight. Then close the superheater drain cock and open the blow-back cock and the superheater valve, and blow steam back into the tank through the feedpipe until the oil is heated.

TYPE C-2 LOCOMOTIVE BOOSTER

Serial 2355 Edition 1

GENERAL DESCRIPTION

CONSTRUCTION AND OPERATION

1. Introduction.—All the wheels of a locomotive are capable of exerting traction, thereby developing drawbar pull, provided that a turning force can be imparted to them. The general practice has been to use only the driving wheels for this purpose, and make no use of the trailing truck or the tender truck wheels. The steam pressure in the cylinders is transmitted through the main rods to the main drivers, from which the turning effort is transmitted to the other drivers through the side rods. Obviously, only wheels of the same diameter, and hence of the same circumferential speed, can be connected by side rods, and this makes it impossible to couple up the wheels of the trailing truck, which carry a considerable part of the weight of the locomotive, to the rear driving wheels. Therefore, a turning impulse must be imparted to the truck wheels by other means, as by the locomotive booster.

2. Purpose.—The purpose of the locomotive booster is to increase the drawbar pull of the locomotive. It is a simple non-reversible two-cylinder engine, which is mounted on the trailing truck, and is so arranged as to transmit through a system of gears a turning impulse to the trailing-truck wheels, when cut into service. A greater drawbar pull is required to start trains than to haul them, therefore the use of the booster enables heavier trains to be started, and thereby increases the hauling capacity of the locomotive. Also, the booster makes it possible to start trains more smoothly, to bring them up to

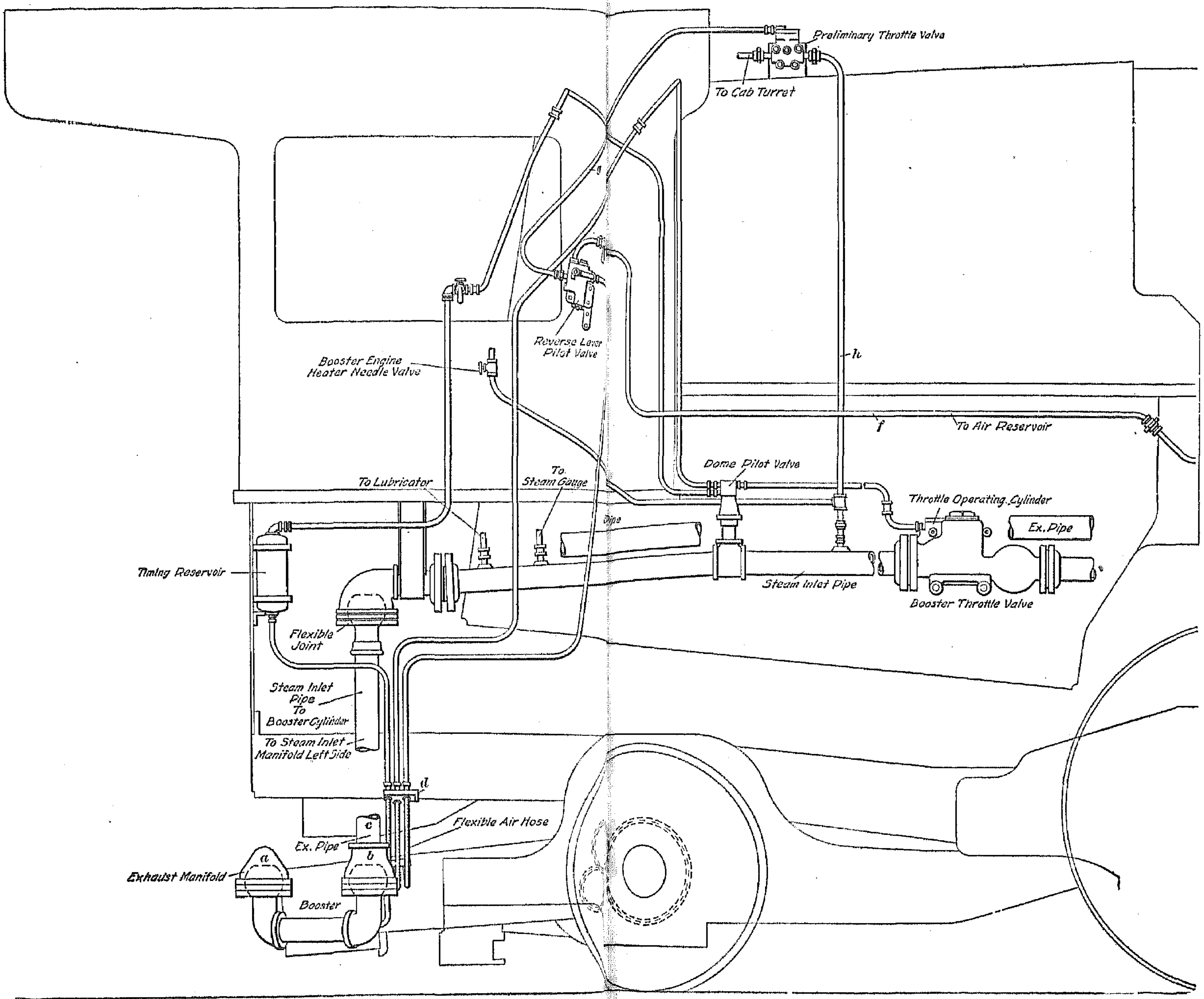
speed more quickly, and to pull trains on grades where a helper otherwise would be required.

3. Types of Boosters.—The first type of locomotive booster, manufactured by the Franklin Railway Supply Company, Inc., was known as the type C. A later type was known as the C-1, and a still later type as the C-2. The principal difference in the different types is in the booster control or the parts concerned with the cutting-in and the cutting-out of the booster. Only the type C-2 locomotive booster will be treated here.

4. Names of Parts.—A view of the locomotive booster mounted on the trailing truck, together with the various valves and the piping necessary for its operation, is shown in Fig. 1. The names of the valves are as follows: Booster throttle valve and throttle operating cylinder, located in the steam-inlet pipe to the booster; the preliminary throttle valve, piped to the cab turret; the dome pilot valve in the steam-inlet pipe; and the reverse-lever pilot valve, located at the reverse lever.

The exhaust pipe to the booster engine, which is only partly shown, is placed on the right side of the locomotive, and the steam-inlet pipe is placed on the left side. Hence Fig. 1 shows the piping as viewed from the right side with the boiler removed. The exhaust pipe at the rear is flexibly connected to an exhaust manifold on the right side of the booster, and the steam-inlet pipe is connected to a similar manifold, not shown, on the other side of the booster. With the arrangement shown in Fig. 1, the booster engine is operated by superheated steam taken from the steam chests of the locomotive.

5. General Arrangement.—In Fig. 2 (*b*) is shown the arrangement, at the front end of the locomotive, of the steam pipe through which steam is conveyed to the booster engine, as well as of the exhaust pipe that conveys the steam away from the booster engine. An opening is provided in each steam chest, into which are screwed the fittings *a*, connected by the pipe *b* so that steam will be drawn equally from each steam chest. The steam-inlet pipe *c*, view (*a*), is connected to the


Preliminary Throttle Valve
To Cab Turret
Reverse Lever Pilot Valve
Booster Engine Heater Needle Valve
h
f
To Air Reservoir
Dome Pilot Valve
To Lubricator
To Steam Gauge
Throttle Operating Cylinder
Ex. Pipe
Timing Reservoir
Steam Inlet Pipe
Booster Throttle Valve
Flexible Joint
Steam Inlet Pipe To Booster Cylinder
To Steam Inlet Manifold Left Side
d
Flexible Air Hose
c
Ex. Pipe
a
b
Exhaust Manifold
Booster

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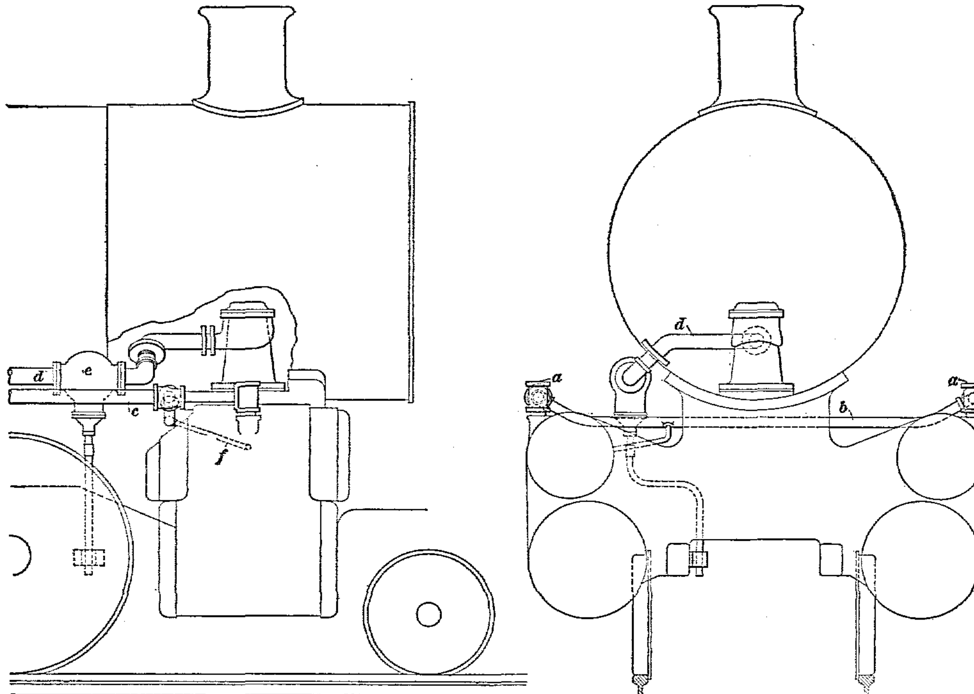


(a)

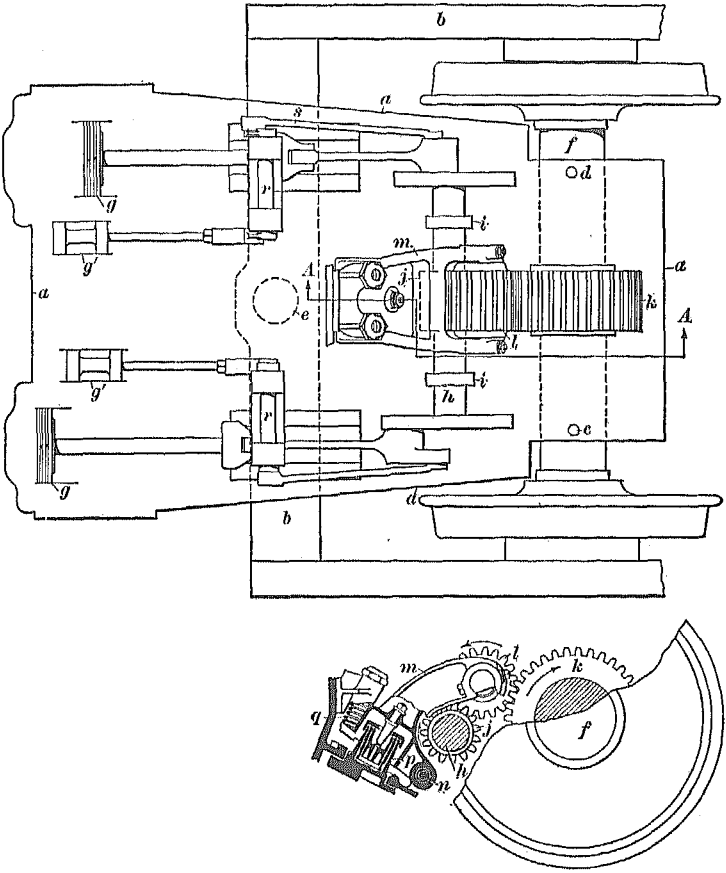
(b)

Fig. 2

pipe *b* by a steel T, and leads back along the left side of the locomotive to the booster engine. The exhaust pipe *d*, on the right side of the locomotive, conveys the exhaust steam from the booster engine to the exhaust pipe. A steam separator *e* with a drain pipe is installed in the exhaust piping, and a drain pipe *f* is also tapped into the pipe *b*. Flexible joints are provided at *a* and *b*, Fig. 1, in the exhaust piping as well as at the upper end of the vertical length *c*, so that this pipe as well as the pipe to the manifold, can accommodate themselves to the varying positions of the booster as the trailing truck is rounding curves or is moving up and down on its springs. The steam-inlet pipe is also provided at the rear with three flexible joints similar to the joints in the exhaust piping. The steam and exhaust pipes have an internal diameter of 3½ inches.

Three air pipes are connected to a manifold *d*, which in turn is connected to the booster by means of the flexible air hose shown. One pipe leads to the reverse-lever pilot valve, another leads to the dome pilot valve with a branch to the throttle operating cylinder of the main booster throttle, and the third pipe connects to the timing reservoir and then leads to the dome pilot valve. The air supply for the operation of the various valves is taken from the main reservoir through the pipe *f* that connects to the reverse-lever pilot valve. An air pipe *g* connects the reverse-lever pilot valve to the preliminary throttle valve, and a steam pipe *h* leads from this valve to the steam-inlet pipe to the booster; also, a pipe connects the preliminary throttle valve to the cab turret. A pipe that leads to the lubricator and another that leads to the steam gauge are tapped into the steam-inlet pipe.

6. General Operation of Booster.—The complete locomotive booster comprises two principal units, the booster engine and the booster control. It will be found more convenient when studying the general operation of the booster to disregard the booster control and consider the booster engine only. A conventional arrangement of the booster engine that will make the arrangement and general operation of this part more



Section A-A

FIG. 3

easily understood is shown in Fig. 3. The booster engine bed, which is represented by the lines *a*, is placed on the frame of the trailing truck, indicated by the lines *b*. The engine bed makes a bearing with the cross-member of the truck frame at *e* and with the trailing-truck axle at *c* and *d*. The bearing at *e* is spherical and is so arranged that as the trailing-truck axle tilts on curves and moves momentarily independent of its frame, the booster engine bed can roll freely on the point *e*. The booster engine proper consists of two steam cylinders *g* and two steam chests *g′* with pistons and valves and connecting-rods as shown, the latter being connected to cranks on the crank-shaft *h*. The valve rods are connected through rockers *r* and eccentric rods *s* to eccentrics on the crank-shaft cranks. The cylinders are bolted to the engine bed and the crank-shaft turns within the bearings *i* in the bed. A gear *j* is cut on the crank-shaft *h*, and a gear *k* is pressed on to the trailing-truck axle. An idler gear *l* is connected to an idler-gear rocker *m* that is pivoted at *n*.

7. When the locomotive is running with the booster cut out, all the parts of the booster engine are stationary and the trailing-truck axle *f* turns freely within the bearings *d* and *c* of the engine bed. As soon as the booster is cut in, steam enters the steam chests and is distributed by the valves to the cylinders, as with any steam engine. The pistons accordingly are moved to and fro in the cylinders, and the connecting-rods transmit a turning movement to the crank-shaft *h* and the gears *j* and *l*, in the direction shown by the arrows. At about this time, air is admitted to the clutch cylinder *p*, the piston within it is forced up and the idler gear *l* is brought into mesh with the trailing-truck axle gear *k*. The idler gear now connects the two gears *j* and *k*, hence the force exerted by the booster engine in turning the shaft *h* is transferred through the gear *k* on the trailing-truck axle to the trailing-truck wheels, thereby converting them into driving wheels. The arrow on the trailing-truck axle gear shows its direction of movement. The booster is cut out by releasing the air from the cylinder *p*, the spring *q* then returns the piston to release position, and the

idler-gear rocker pulls the idler gear *l* out of mesh with the gear *k*.

8. Booster Engine Not Reversible.—The booster runs in one direction only and cannot be reversed; that is, the booster, when cut in, will assist the locomotive to move forwards, but will oppose any movement of the locomotive to move backwards. The eccentrics cranks and hence the valves of the booster engine are so set that the crank-shaft *h*, Fig. 3, and the crank-shaft gear turn in the direction shown by the arrow when the booster is cut in. This causes the idler gear *l* and the trailing-truck axle gear *k* to turn in the direction shown by their arrows and a turning impulse will be imparted to the trailing-truck wheels with the locomotive moving forwards. Therefore, it is useless to cut the booster in when running backwards because its turning impulse is then contrary to the direction of motion of the locomotive. The booster when operated according to instructions cannot be cut in when backing up.

DESCRIPTION OF PARTS

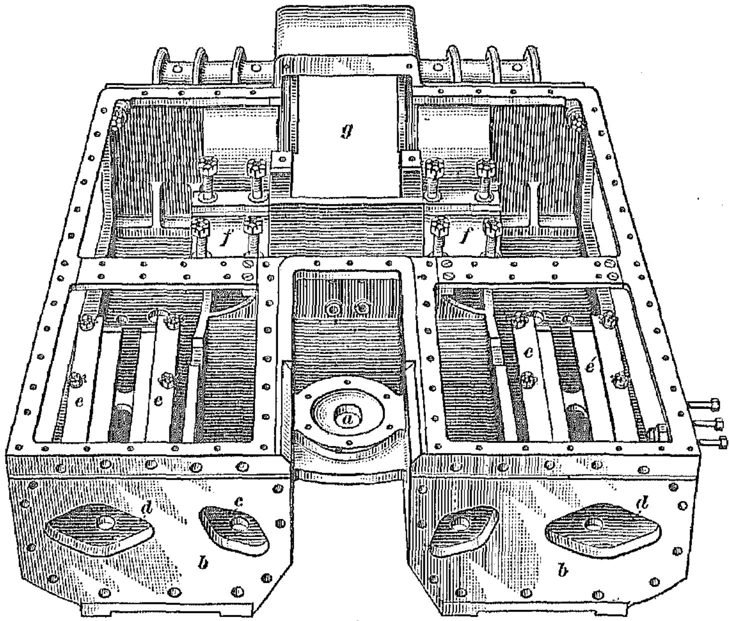
BOOSTER ENGINE

9. Engine Bed.—The engine bed of the booster engine rests on the trailing truck. A perspective view of the engine bed is shown in Fig. 4 (*a*) and a view of the axle bearing cap is shown in (*b*). The engine bed is covered on the sides and the top by cover-plates, here shown removed.

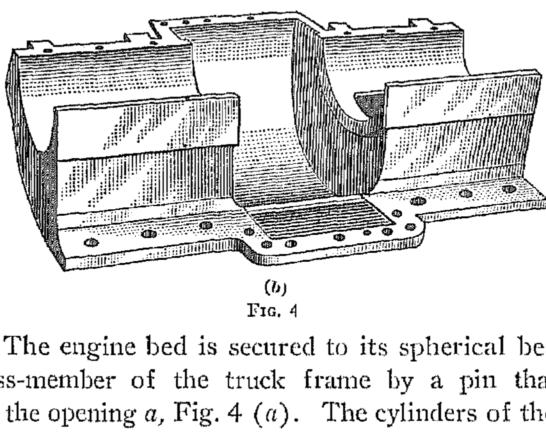
The engine bed is carried on the trailing truck on three points, two of which are on the trailing-truck axle and the third one on the cross-member of the trailing-truck frame at the rear. Suitable bearings are provided in the engine bed at the two points where it is carried on the axle. The bearing at the rear is spherical and it therefore permits a free movement of the booster on the cross-member of the frame according as one or the other of the trailing-truck wheels raises or lowers. Owing to this movement, the lubrication of this bearing should not be neglected.

The engine bed is held in position on the axle by the axle bearing cap. This cap is also provided with bearings so that,

when bolted in place, the bearings in the cap and in the bed constitute two complete bearings that encircle the trailing-truck axle.



(a)



(b)

Fig. 4

10. The engine bed is secured to its spherical bearing on the cross-member of the truck frame by a pin that passes through the opening *a*, Fig. 4 (*a*). The cylinders of the booster engine are bolted to the face *b* of the bed, and the openings *c* are provided for the valve rods, and the openings *d* for the

piston rods. The crosshead guides are shown at *e* and the half bearings for the booster engine crank-shaft are shown at *f*; the large gear on the trailing-truck axle projects into the opening *g* in the engine bed. The engine bed on the top and sides is covered by a casing that is held in position by studs and nuts.

A side view of the front part of the engine bed is shown in Fig. 5, with the axle bearing cap *b* bolted to it by the bolts

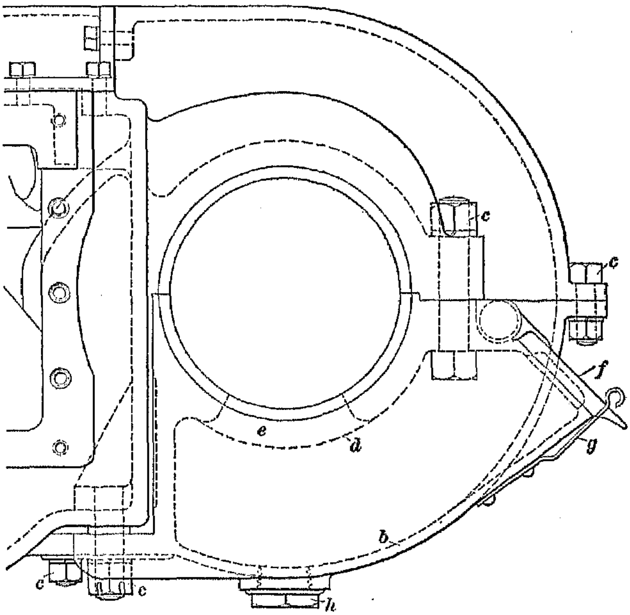


FIG. 5

and studs *c*. Each end of the axle bearing cap is provided with an oil cellar, the outline of one being shown by the dash line *d*. Each oil cellar is connected to the trailing-truck axle through a slot *e* that is cut through the bearing in the axle bearing cap. The cellars are filled with oil-soaked waste through the two covers *f* that are held closed by the springs *g*. Each cellar can be drained of oil by removing a plug *h*, but the plug has only to be turned part way out to allow any water that may have accumulated to drain out. With the top and side cover-plates

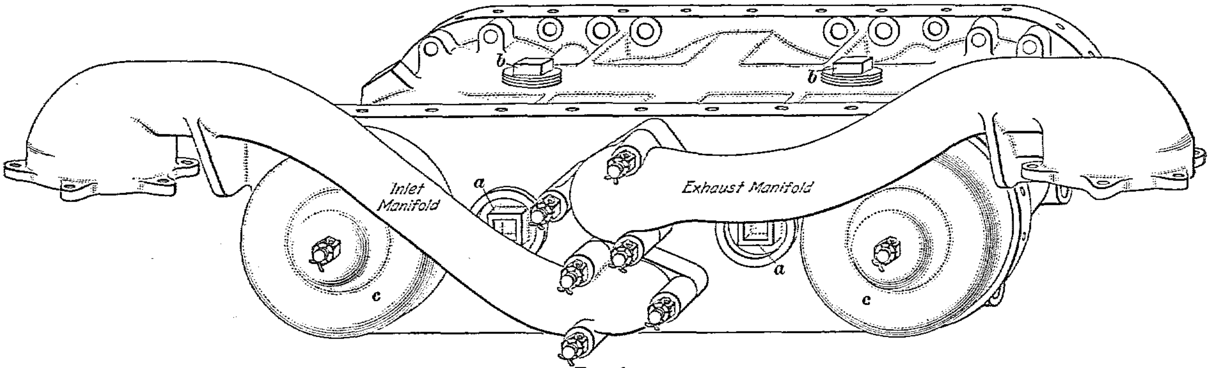


FIG. 6

applied, the engine bed becomes an oil-tight case, so that the splash method of lubrication is employed to lubricate all the moving parts of the engine except the pistons and the valves. Car oil is used, and this is poured in through two oil-filling plugs, placed at the back outside corners of the back top cover-plates. Two oil overflow drain cocks at the front end of the engine bed indicate the height at which the oil should be maintained. Before replenishing the oil supply, the oil plugs in the crank-pits and the axle bearing cap should be backed out a turn or two to permit any water to drain out through the small holes in the plugs. The oil plugs should not be removed unless necessary to drain off the oil.

11. Cylinder Casting.—A perspective view of the cylinder casting that contains the cylinders and the steam chests as viewed from the rear is shown in Fig. 6. No front cylinder heads are used, the front ends of the cylinders being made in one piece with the casting. This construction permits the part of the casting that contains the cylinders to be bolted directly to the engine bed, thereby providing a fastening directly in line with the main thrust of the pistons. The back ends of the cylinders are closed by cylinder heads, and the steam chests are closed by large plugs *a*, which are screwed into the casting. The covers *c* are connected to the cylinder heads as shown. The plugs *b* were formerly used for core fixing and cleaning when casting but are not found in the latest castings.

The steam from the steam pipe enters the casting through the inlet manifold and thence passes through passages in the casting to the steam chests. The exhaust steam passes from the cylinders through passages in the casting to the exhaust manifold and to the exhaust pipe. The inlet and exhaust manifolds are separate and are bolted to the cylinder casting. The cylinders are 10 inches in diameter; the stroke is 12 inches.

12. Crank-Shaft and Crank-Arms.—A perspective view of the crank-shaft *h*, Fig. 3, and the crank-arms, is shown in Fig. 7. The crank-shaft and the gear *a* are made in one piece; that is, the shaft is forged with a raised portion in the center in which the gear-teeth are then cut. The bearing parts of the

shaft, or the parts adjacent to the crank-arms *c*, turn partly in the bearings in the engine bed and partly in the caps that, when bolted in position, secure the shaft to the bed. The

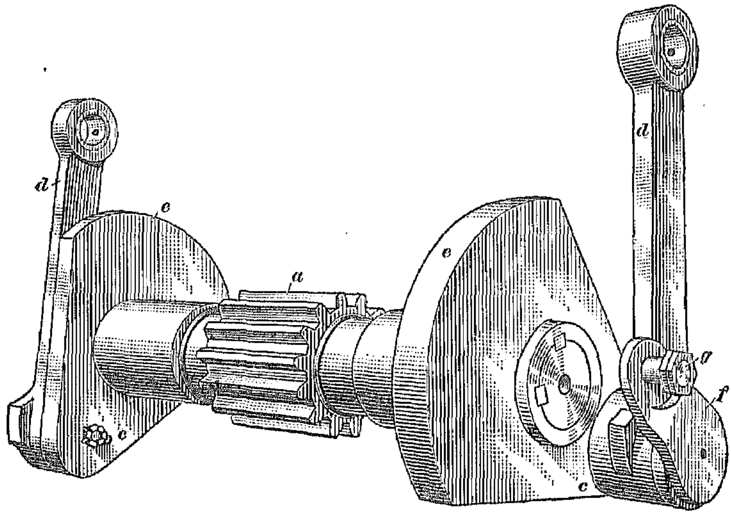


FIG. 7

crank-arms *c* and their pins on which the connecting-rods *d* are mounted, are made in one piece. The crank-arms, which have counterbalances *e*, are pressed onto the ends of the crank-shaft and each is further secured by two keys. Each eccentric crank *f* is secured to its crankpin by a four-key spline *d*, Fig. 8, that passes through and meshes with keyways machined in the crankpin. The eccentric crankpin *g*, Fig. 7, is made in one piece with the eccentric crank.

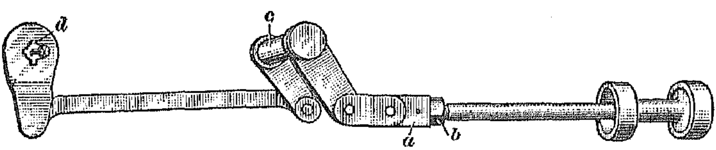


FIG. 8

13. Valve Gear.—A view of the valve gear of the booster engine is given in Fig. 8. The valve gear for each cylinder comprises an eccentric crank, an eccentric rod, a rocker-arm, a

wristpin block, a valve stem, and a valve. The valve stem can be lengthened or shortened by driving out the tapered pin *a*, loosening the locknut *b*, and then turning the valve stem in the proper direction in the wristpin block. No packing rings are used on the valves, which are inside admission. The part *c* of the rocker-arm rotates in a bearing in the engine bed. The valves of the booster engine are set to cut off the admission of steam to the cylinders at either 75 per cent. or 50 per cent. of the stroke. In the latter case the valves are modified so as to obtain the same cylinder pressure when starting as with the longer cut-off, but after the speed increases slightly the valves

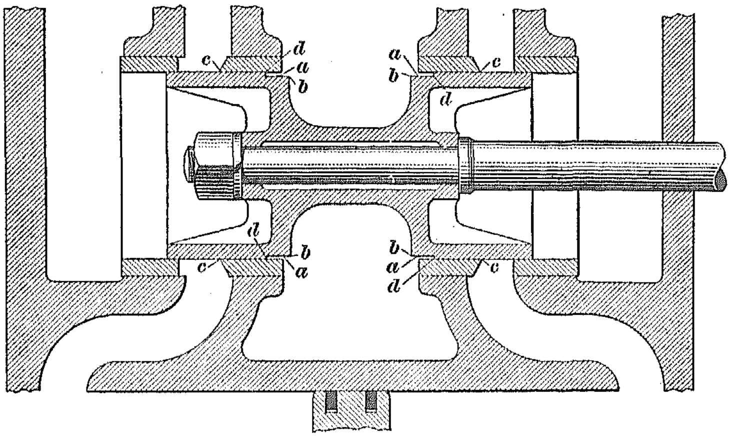


FIG. 9

then operate at a 50-per-cent. cut-off. With this valve arrangement, the booster engine is said to have the limited cut-off feature. The reason for the use of this feature is the large saving in steam that results, which more than offsets the lesser power developed by the booster, especially at low speeds.

14. The changes in the valve necessary to obtain a 50-per-cent. cut-off when running at speed, and a long cut-off when starting is shown in Fig. 9. In this connection it should be remembered that an increase in the steam lap of a valve shortens the cut-off and that a decrease lengthens it. In Fig. 9 the valve has a steam lap, that is, the inside edges of the valve

extend over the ports; also these portions of the valve have been reduced at *a*.

With the valve moving slowly as when starting the booster, the effect of the reduced portion of the valve will be the same as if the steam lap had been reduced, because the steam will continue to pass by the reduced end even after the edge *b* moves over the edge *c*. In this case the edge *d* governs the cut-off. With the valve moving more rapidly, as when the speed of the booster increases, the steam does not have as much time to pass by the part *a*; the edge *b* then governs the cut-off, which is thereby reduced, because the valve is now operating with a greater steam lap than at slow speed.

BOOSTER CONTROL SYSTEM

15. Purpose.—The purpose of the booster control system, which comprises an arrangement of valves, piping, and other parts, is to provide a means of cutting the booster into and out of operation. The parts that make up the booster control system, shown in section, as well as the air piping arrangement, is shown in Fig. 10. The parts comprise the idler-gear rocker, the idler gear, and the clutch cylinder, all of which parts are in the engine bed; the reverse-lever pilot valve, the preliminary throttle valve, the dome pilot valve, the main booster throttle with a throttle-operating cylinder, and the cylinder-cock operating cylinder.

16. Idler-Gear Rocker and Gear.—The purpose of the idler-gear rocker is to move the idler gear into and out of mesh with the gear on the trailing-truck axle. The purpose of the idler gear is to cut the crank-shaft gear into and out of mesh with the gear on the trailing-truck axle.

A perspective view of the idler-gear rocker with the idler gear mounted on it is shown in Fig. 11. The idler gear turns on a shaft *b* that is held in the rocker by a bolt in each end. The idler-gear rocker is connected to the engine bed by a pin *a*, Fig. 10, that passes through the opening *a*, Fig. 11. The relation of the idler gear to the crank-shaft gear and the trailing-truck axle gear is shown in Fig. 10. The idler gear is always

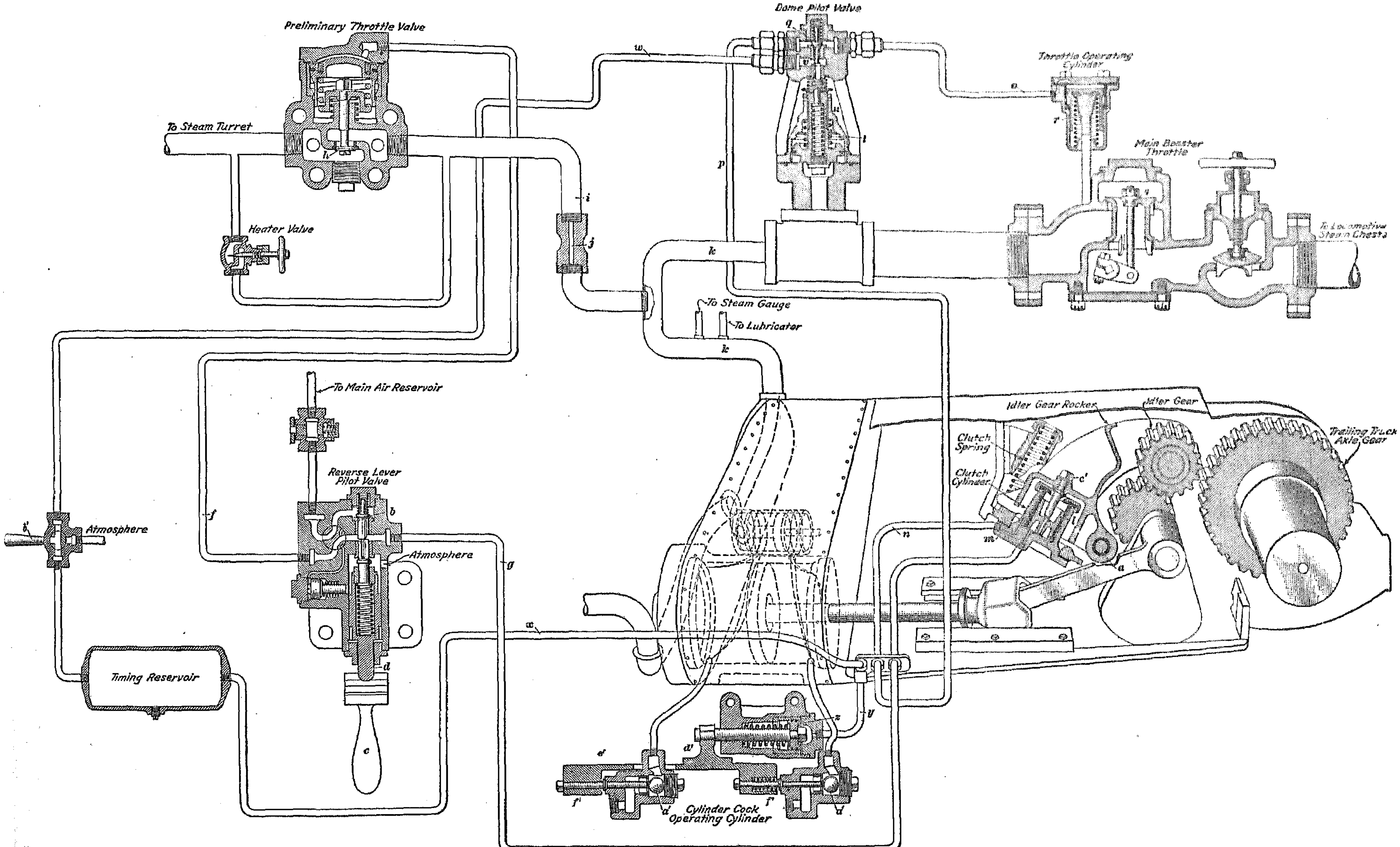

Preliminary Throttle Valve
Dome Pilot Valve
Throttle Operating Cylinder
Main Booster Throttle
To Locomotive Steam Chests
To Steam Turret
Heater Valve
To Steam Gauge
To Lubricator
To Main Air Reservoir
Reverse Lever Pilot Valve
Atmosphere
Atmosphere
Timing Reservoir
Idler Gear Rocker
Idler Gear
Trailing Truck Axle Gear
Clutch Spring
Clutch Cylinder
Cylinder Cock Operating Cylinder

Fig. 10

in mesh with the crank-shaft gear, but the idler gear meshes with the gear on the trailing-truck axle only when the booster is cut in. In such an event the idler gear connects the crank-shaft gear with the trailing-truck axle gear, thereby transferring the force that the booster engine is transmitting to the crank-shaft, to the trailing-truck axle gear and to the trailing-truck wheels. At this time the idler-gear rocker carries the idler gear

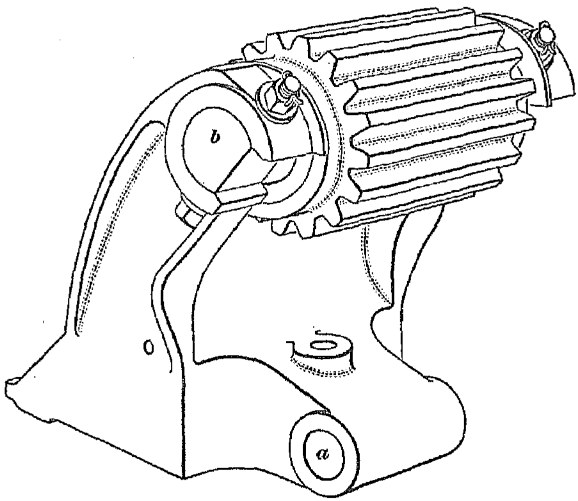


FIG. 11

into mesh with the trailing-truck axle gear when cutting in the booster. When the booster is being cut out, the idler-gear rocker carries the idler gear out of mesh with the trailing-truck axle gear.

17. Clutch Cylinder.—The purpose of the clutch cylinder is to move the idler-gear rocker and bring the idler gear into mesh with the trailing-truck axle gear. An exterior view of the clutch cylinder is shown in Fig. 12. The clutch cylinder is placed in position by inserting the upper cylindrical portion up through an opening in the bottom of the engine bed, where it is secured by bolts through the bolting flange. The cap nut *a* is prevented from turning by the locking arrangement *b*.

A sectional view of the clutch cylinder as well as a part of the idler-gear rocker is shown in Fig. 13; the only moving part is the piston *j*. The passages *a* and *b* in the engine bed connect with the passages *c* and *d* in the clutch cylinder when the latter is bolted in place. This arrangement permits the clutch cylinder to be removed and applied without disturbing the pipes. The clutch cylinder cannot be applied without the air passages in the engine bed matching with the air passages in the clutch cylinder, owing to the fact that the rear clutch-cylinder stud in the engine bed between the air ports is longer than the other

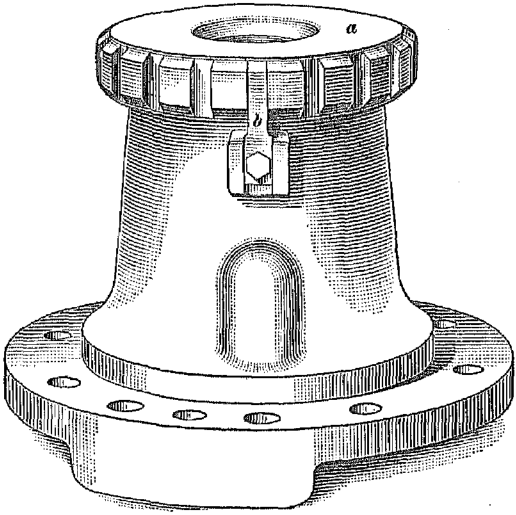


FIG. 12

studs. The gasket *e* prevents leakage between the air passages, and care should be taken when applying the gasket to see that the holes in the gasket match with those in the engine bed. Otherwise, one or both ports will be blanked and the booster will not operate.

The idler-gear rocker is brought back to normal position after operation by the two clutch springs *f*, the lower ends of which rest in shoes cast with the rocker. The springs are housed in the clutch-spring retainer *g*, which is bolted to the engine bed. The springs are held in place by retainer caps *h*,

which are prevented from backing off by wire locks *i* through the caps and the retainer casting.

18. The admission of compressed air to the clutch cylinder through the passage *c* forces the piston *j* upwards as in Fig. 13 (*a*), and causes it to engage the lifting post *k* in the idler-gear rocker *l*, thereby lifting the rocker and bringing its gear into mesh with the trailing-truck axle gear. The upward movement of the rocker also places the clutch springs under compression.

The upward movement of the piston uncovers the ports *m* in the bushing and permits the air to pass to passage *d* and to the dome pilot valve and the throttle-operating cylinder. Any leakage by the piston is prevented by its seating airtight on the gasket *n*. When the air is exhausted from the clutch cylinder through the pipe that connects to passage *a*, the clutch springs force the idler-gear rocker and the piston back to normal position, as in view (*b*). The air in passage *b* and in the piping connected to it passes around the central part of bushing *o*, which is machined below its fit diameter, and escapes through the ports *p* in the bushing and the open end of the cylinder to the atmosphere. The ports *p* are closed by the piston when it moves upwards and the air that enters around the bushing at this time from ports *m* is prevented from escaping.

19. When the gear on the idler-gear rocker and the gear on the trailing-truck axle are fully in mesh, there is a clearance of from $\frac{1}{16}$ inch minimum and $\frac{1}{8}$ inch maximum between the top of the pin *q*, Fig. 13 (*a*), in the piston and the lifting post *k*. Therefore, the piston does not carry the rocker gear into complete mesh with the trailing-truck gear; it merely carries the rocker a portion of its travel from release to application position, and the rocker travels the remaining distance owing to the idler gear pulling itself fully into mesh by hooking under a tooth of the axle gear. The piston in the clutch cylinder is then held against the gasket by air pressure only. The forward movement of the rocker is limited by the flat faces of the idler-gear bearing pin, Fig. 11, striking the rocker stops in the engine-bed casting when the gears are completely in mesh.

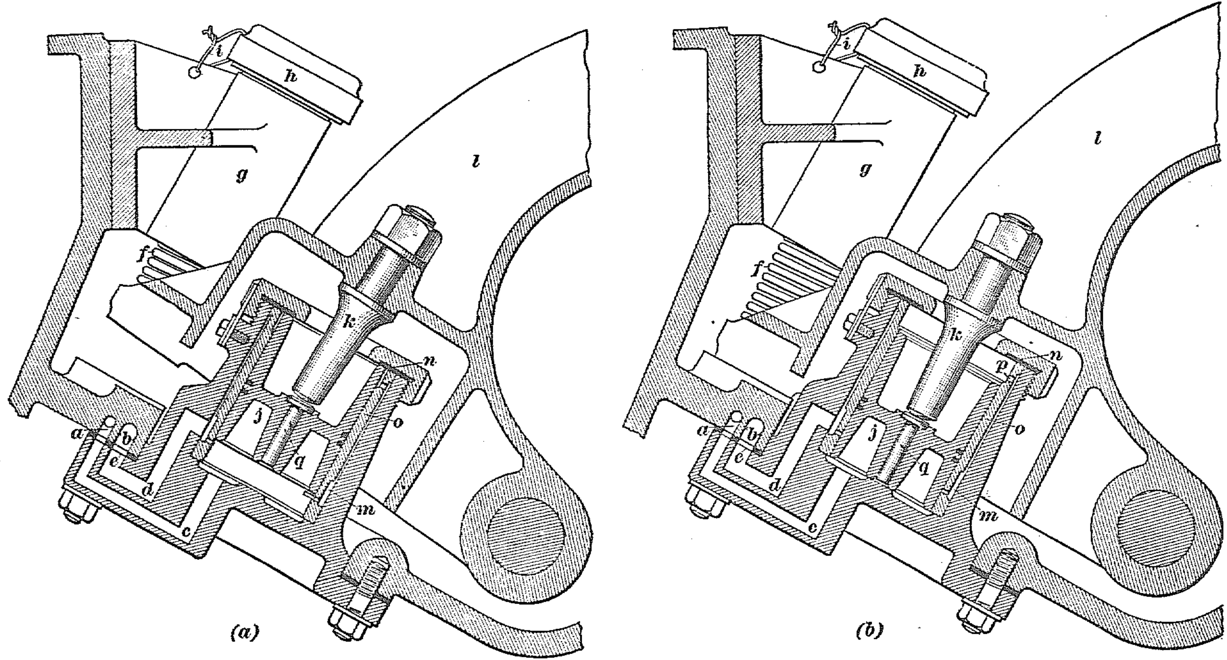


FIG. 13

The backward movement of the rocker is limited by the integral shoes for the clutch springs striking the machined pad on the engine bed.

The fact that the engagement of the gear-teeth is relied on to bring the gears into mesh causes the idler-gear rocker to

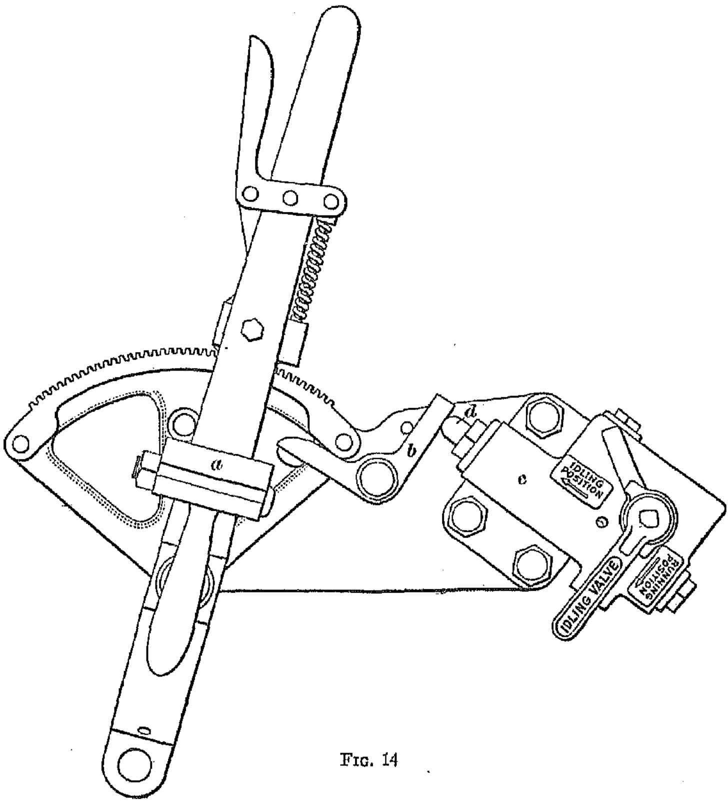


FIG. 14

move back and forth when the booster is removed from the trailing-truck axle and air is applied to the clutch cylinder. The reason is that when the axle gear is not present the clutch springs are of sufficient strength to cause the lifting post to move the piston away from its seat on the gasket. The release of the air that follows allows the rocker to return to its back stop, but the air pressure on the piston again moves the rocker

to its forward stops. This movement will continue unless the rocker is held in forward position by the hand.

20. Arrangement at Reverse Lever.—The arrangement of the parts at the reverse lever whereby the booster is cut in and out is shown in Fig. 14. The arrangement comprises a

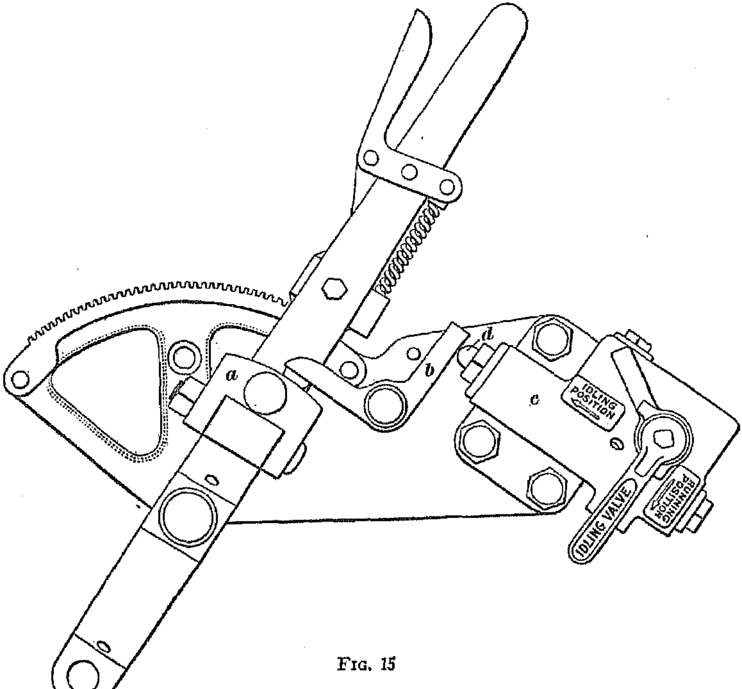


Fig. 15

booster latch *a*, pinned on the reverse lever, a latch lever *b*, pinned to a steel plate fastened to the forward end of the reverse-lever quadrant, and a reverse-lever pilot valve *c*, which is also bolted to the steel plate. These parts control the cutting in and out of the booster in the following manner: With the reverse lever at or near the forward corner of the quadrant, Fig. 15, and with the booster latch *a* raised as shown, the latch lever will be forced against and will depress the spring cage *d* in the reverse-lever pilot valve. This action will result in the

admission of compressed air to the control system, and the booster will begin to operate.

The booster latch will remain in contact with the latch lever and the booster will continue to operate until the reverse lever has been drawn back to about a 66-per-cent. cut-off, as shown in Fig. 14. The booster latch then drops out of contact with the latch lever, and the spring cage returns to normal position. This action causes the compressed air to be exhausted from the control system and the booster is cut out of operation. Therefore, the booster cuts in when the spring cage is depressed and cuts out when the spring cage seats.

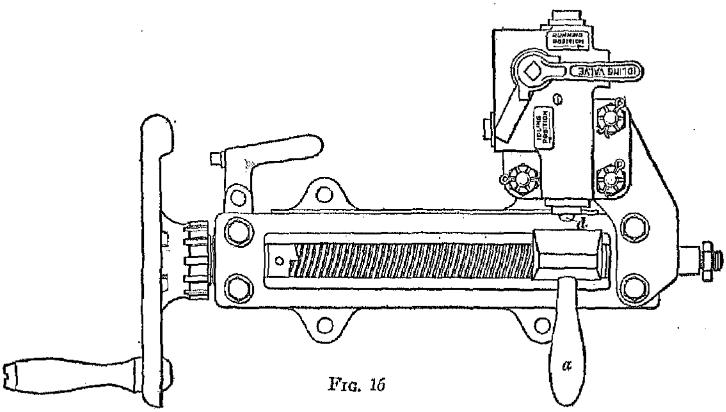


FIG. 16

With the Precision reverse gear, Fig. 16, the reverse-lever pilot valve is applied as shown, and the booster latch *a* is placed on an extension arm of the indicator block. With the indicator block at or near the forward corner, the booster latch when raised will engage with and depress the spring cage *d*, thereby cutting in the booster. As the indicator block is moved back by turning the hand wheel, the booster latch will drop out of contact with the spring cage and the booster will stop operating. The booster latch, if desired, can be knocked down out of contact with the latch lever at any time, hence the reverse lever does not always have to be drawn back to disengage the latch.

21. Reverse-Lever Pilot Valve.—The purpose of the reverse-lever pilot valve is to admit compressed air into the

control system of the booster when the booster latch is raised, thereby bringing about the operation of the various valves necessary to put the booster to work. Also, the reverse-lever pilot valve, when the booster latch is lowered or knocked down, exhausts the compressed air from the control system and causes the various valves of the system to so operate as to cut out the

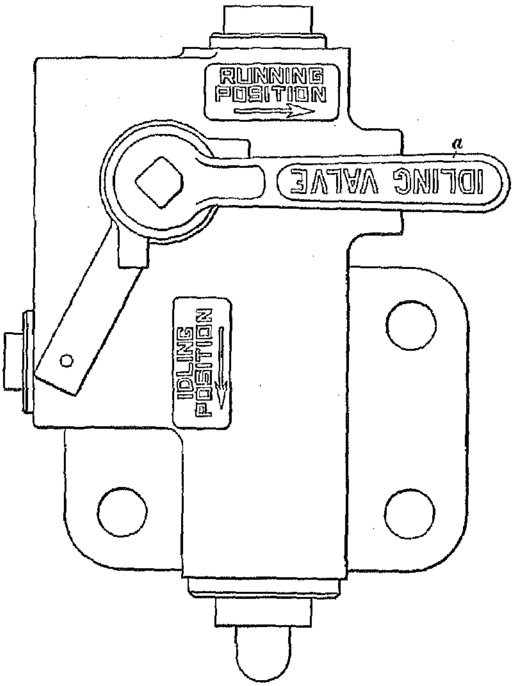


FIG. 17

booster. An exterior view of the reverse-lever pilot valve in the proper position to be applied to the Precision power reverse gear is shown in Fig. 17. The valve handle *a* is used to operate a plug valve called the idling valve. This valve has two positions; running position, with the handle as shown, and idling position, with the handle vertical. These two positions are indicated by the raised letters and the arrows on the body of the valve. Idling position is used to warm the booster engine up before cutting it into service. For example, before

the booster is to be used, the handle of the idling valve is placed in idling position. The booster engine then begins to turn over without going into gear with the gear on the trailing-truck axle. After the engine is warmed up, the handle is returned to running position, and this position when the booster latch is raised cuts the booster engine into gear with the trailing-truck axle gear. The booster latch cannot be raised when the handle of the idling valve is in idling position.

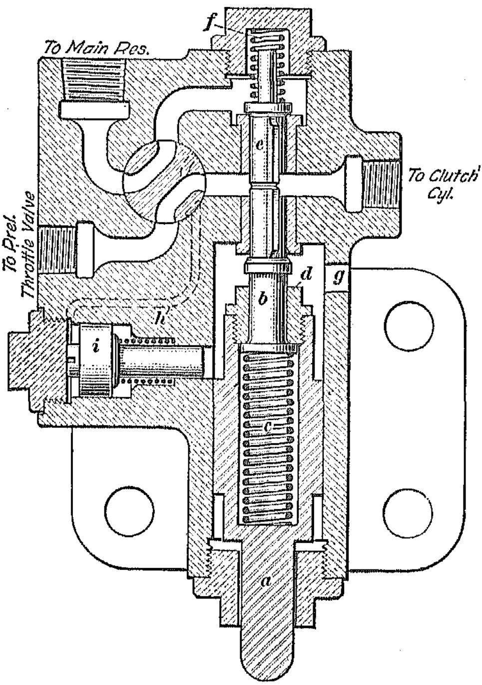


FIG. 18

22. A sectional view of the reverse-lever pilot valve is given in Fig. 18. Three pipes are connected to the valve; one pipe leads to the clutch cylinder, another to the preliminary throttle valve, and the third to the main reservoir. The reverse-lever pilot valve comprises the following parts: A spring cage *a*, a valve pusher *b*, and a pusher spring *c*, all held in position in the cage by the nut *d*; an inside check-valve with an

enlarged circular lower end, the bottom of which rests on the end of the valve pusher and the top of which makes a seat with the bushing above it when the valve closes; an outside check-valve *e*, a check-spring *f*, and a locking piston *i*. As the spring cage is raised by the pressure of the booster latch against its projecting lower end, the inside check-valve is moved up against

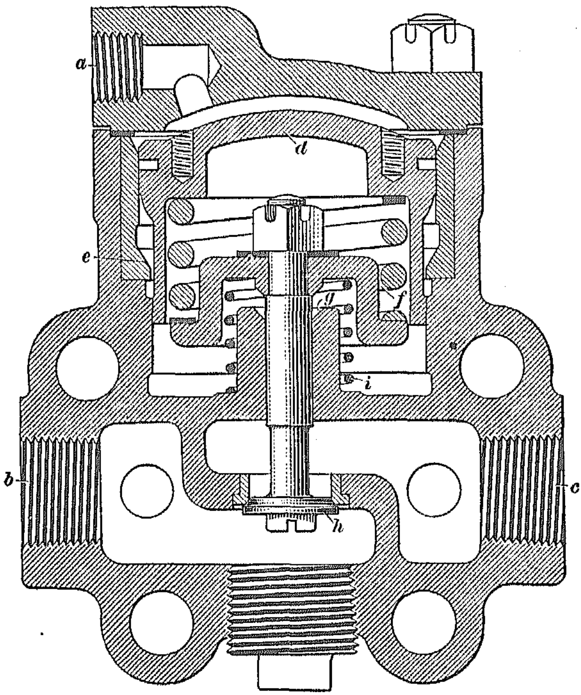


Fig. 19

its seat by the valve pusher *b*, and in so doing lifts the outside check-valve *e* from its seat. Then any further movement of the spring cage will carry the nut *d* upwards, with the result that the spring *c* will be compressed, thereby holding the inside check-valve firmly to its seat through contact with the valve pusher *b*. With the outside check-valve unseated, the main reservoir will be connected to the clutch-cylinder pipe and the preliminary throttle-valve pipe. The spring cage will be forced back to normal position by the pusher spring when the booster

latch drops down; the inside check-valve will then open and the outside check-valve will close. With the inside check-valve open, the preliminary throttle-valve pipe and the clutch-cylinder pipe are connected through port *g* to the atmosphere. With the idling-valve handle turned to idling position, the plug cock shown turns and connects the main reservoir pipe to the preliminary throttle-valve pipe, also air from the main reservoir passes through passage *h* behind the locking piston *i* and moves it forwards against the spring cage, preventing it from being depressed.

23. Preliminary Throttle Valve.—The purpose of the preliminary throttle valve is to admit a limited amount of steam to the booster engine when starting it. The preliminary admission of steam not only turns the engine over slowly and warms it up, but it also causes the idler gear to turn and exert enough tooth pressure to pull it into mesh with the trailer gear when both gears are brought into contact. The preliminary throttle valve also provides a safe means for idling the booster for inspection.

A sectional view of the preliminary throttle valve is shown in Fig. 19. Port *a* is connected by an air pipe to the reverse-lever pilot valve, a steam pipe from the cab turret is connected at *b*, and a pipe connects the opening *c* to the steam-inlet pipe.

The admission of compressed air above the piston *d* forces it down to a seat at *e* and prevents the leakage of any air that may pass by the packing ring. The downward movement of the piston compresses the spring *f* and moves the spring seat down to its seat at *g*, at the same time opening the steam valve *h*. When the air pressure is released, the spring *f* returns the piston to normal position, and the spring *i* moves the spring seat upwards, thereby closing the steam valve. An opening, not shown, is provided to permit any steam to escape that may leak by, owing to a failure of the spring seat to make a joint at *g*.

24. Dome Pilot Valve.—The dome pilot valve controls the opening and the closing of the cylinder cocks. When starting the booster, the dome pilot valve delays the closing of

the cylinder cocks long enough to insure that the cylinders are free of water. Also, when cutting out the booster, the dome pilot valve exhausts the compressed air from the cylinder-cock piping, and permits the cylinder cocks to open.

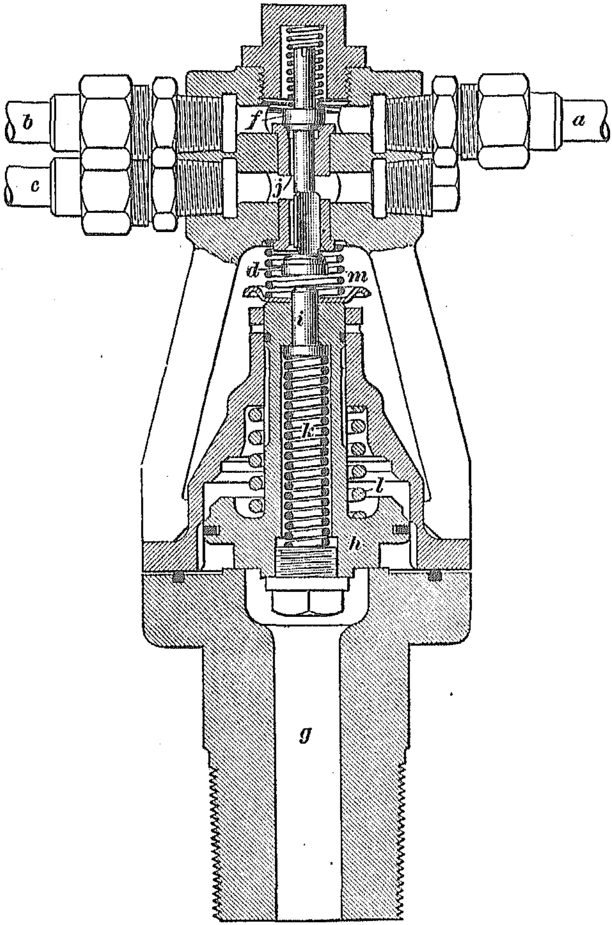


FIG. 20

The dome pilot valve as shown in the sectional view in Fig. 20 has three pipes connected to it. The pipe *a* leads to the throttle operating cylinder of the main booster throttle, the pipe *b* leads to the clutch cylinder, and the pipe *c* leads to the

cylinder-cock operating cylinder. The threaded end of the valve is screwed into the steam-inlet pipe that leads to the booster. The top of the valve is joined to the bottom by four ribs, hence the central portion of the valve is open to the atmosphere through the openings between the ribs.

To understand the action of the dome pilot valve, it must be remembered that the cylinder cocks of the booster engine close when compressed air is admitted to the cylinder-cock operating cylinder pipe, and that they open when the air is exhausted from the pipe.

In normal position of the dome pilot valve as shown, the cylinder-cock operating cylinder pipe *c* is connected by way of the unseated inside check-valve *d* to the atmosphere; therefore the cylinder cocks are open. The outside check-valve *f* is held closed by its spring. The clutch-cylinder pipe *b* and the throttle operating-cylinder pipe *a* are always connected by a passage above the outside check-valve.

When starting the booster engine, the preliminary throttle valve opens, the engine begins to turn over slowly, and any condensed water in the cylinder discharges through the cylinder cocks, which are now open. At the same time air passes from the clutch-cylinder pipe *b* to the throttle operating-cylinder pipe *a*, thereby causing the throttle operating cylinder to begin to open the booster throttle valve. Steam then enters passage *g* in the dome pilot valve, forcing the piston *h* upwards, and causing the valve pusher *i* not only to close the inside check-valve *d*, but to open the outside check-valve *f*. Compressed air then passes from the clutch-cylinder pipe *b* through a $\frac{1}{32}$-inch port *j* in the outside check-valve bushing to the cylinder-cock operating cylinder pipe *c* and causes the cylinder cocks to close. Therefore, the cylinder cocks remain open until steam begins to pass to the booster engine in a good volume.

The inside check-valve is held closed by the pressure of the pusher spring *k* under the valve pusher, and thereby prevents the air in the cylinder-cock operating cylinder pipe from escaping to the atmosphere. When the booster is cut out, the steam pressure decreases in passage *g* and the action of the springs *l* and *m* return the piston *h* to normal position. The

outside check-valve *f* closes and unseats the inside check-valve *d*, the air in the cylinder-cock operating cylinder pipe *c* escapes to the atmosphere past valve *d*, and the cylinder cocks open, owing to the fingers pushing the balls from their seats.

25. Booster Throttle Valve.—The purpose of the booster throttle valve is to control the steam supply to the steam-inlet pipe that leads to the booster engine. The throttle valve is operated by the throttle operating cylinder.

A view of the throttle-valve body partly broken away so as to show the throttle valve *a* and the operating cylinder *b* is shown in Fig. 21. The valve rod *c* is pivoted to an arm of

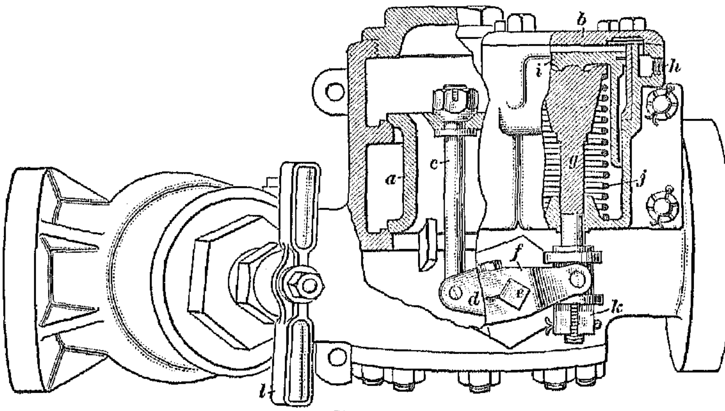


FIG. 21

the operating lever *d* that is connected to the valve operating shaft *e* on the inside of the valve body. On the outside, the outside rocker-arm *f* connects the operating shaft to the end of the spring guide *g* that operates within the piston *i* in the operating cylinder.

The admission of compressed air through port *h* on top of the piston *i* forces the piston down until its seat and the bushing seat are in contact. The escape of air is thus prevented, although there may have been leakage past the piston ring. The spring guide is carried down with the piston, compressing the spring *j* and moving the end of the outside rocker-arm downwards, thus opening the throttle valve. When the air is

released, the spring carries the piston and the end of the outside rocker-arm upwards, thus closing the throttle valve. The spring guide has a spherical surface contact with the piston, which permits free piston movement.

The proper lift of the throttle valve is $\frac{5}{8}$ inch, and is governed by the travel of the piston. The valve operating lever and the outside rocker-arm are of the same length and this facilitates measuring and adjusting the valve lift from the outside.

Air should be used in the operating cylinder when adjusting the valve lift. If the throttle valve is opened by any other means the correct lift will not be obtained. To decrease and increase the valve lift, the adjusting nut *k* should be screwed upwards and downwards, respectively. The steam supply can be shut off from the throttle valve by closing the turret valve *l*.

26. Cylinder-Cock Operating Cylinders.—The cylinder-cock operating cylinders, Fig. 10, one on each side, are secured to bolting lugs on the booster cylinders. They are operated by an air pressure to allow the cylinder cocks to close when the booster is in operation, after the water has been blown from the pipes and cylinders, and to open the cylinder cocks when the booster is not in operation.

Each operating cylinder is provided with a compact operating-rod arrangement for two cylinder cocks. The rear end of the piston rod is connected to a piston-rod block *d′* which in turn connects to the operating rod *e′*. The two finger blocks *f′* carry the operating fingers shown.

In allowing the cylinder cocks to close, the air enters through the pipe *y* and forces the piston *z* backwards until the bevel face of the piston makes a joint against its seat in the bushing. The operating fingers then release the ball valves and the steam pressure forces the balls to their seats in the cylinder-cock bushings.

In opening the cylinder cocks, the air is released from the cylinder, and this allows the spring to force the piston and the operating fingers forwards, thereby unseating the ball valves against the steam pressure and opening the cylinder cocks.

The forward movement of the piston continues until the integral valve on the rear finger seats against the seat on its cylinder cock. The valve on the front finger seats, owing to the pressure of the spring in the counterbored portion of the front finger block.

The operating cylinders are interchangeable to either side of the booster. The cylinder cocks are rights and lefts and are not interchangeable to opposite sides of the booster but are interchangeable to front and back on the same side.

OPERATING INSTRUCTIONS

27. Taking Over Engine.—The following instructions should be observed when the crew takes over an engine at a terminal: (*a*) Set the booster feed for at least two drops per minute to lubricate the cylinders and the valves. (*b*) Open the lubricator feed for about 2 minutes before cutting in the booster, and keep the feed open while the booster is in operation. (*c*) See that the preliminary shut-off valve at the steam turret is open wide. (*d*) See that the booster heater valve is open. This valve should be kept open constantly summer and winter to prevent condensation from forming in the pipes and cylinders and possibly freezing in extremely cold weather. The heater valve also makes prompt operation of the booster possible when it is cut in, as well as to assist in proper lubrication of the cylinders and valves. (*e*) See that the turret valve in the booster throttle valve is open. (*f*) See that the booster air line is open. (*g*) Idle the booster for 2 or 3 minutes before leaving the terminal.

28. Starting the Booster.—Before the booster latch can engage with the latch lever and start the booster, the reverse lever must be between a 66-per-cent. cut-off and the forward end of the quadrant. Then to start the booster, raise the booster latch until it engages the latch lever. Do not cut the booster in at speeds above 12 miles per hour or permit it to remain cut in at speeds greater than 21 miles per hour. Under no conditions is the booster to be used when backing up because the booster engine is designed to turn the trailing-truck wheels in the for-

ward direction only. Should the trailer wheels slip, knock down the booster latch and do not cut in again until the slipping has stopped.

29. Stopping the Booster.—To stop the booster, either draw the reverse lever back until the latch lever drops down, or if it is not desired to change the cut-off by moving the lever, knock the booster latch down. Always cut out the booster before coming to a stop so as to permit the gears to disengage. If the stop is made with the booster cut in, knock down the booster latch, then move the locomotive ahead a few feet and the gears will disengage.

30. Idling the Booster.—To idle the booster, that is, to cause the booster engine to work but not to be in gear with the trailing truck, turn the handle of the idling valve to idling position. The booster should be idled whenever possible before cutting it in.

31. Taking Slack.—When taking the slack with the booster cut in, the engineman should wait, after the reverse lever is moved back, until the hand on the booster steam gauge shows no pressure. The slack can then be taken in the usual way.

32. Cylinder Cocks.—If it is desired to have the cylinder cocks remain open for a longer time than the operation of the cylinder-cock control will permit, turn the handle of cock *b′*, Fig. 10, to a vertical position.

33. Keeping Booster Engine Warmed Up.—To keep the booster engine warmed up when not in use, open the heater needle valve, Fig. 10.

34. Leaving Locomotive at Terminal.—When leaving the locomotive at a terminal, shut off the booster lubricator, and close the booster air-line valve in the main reservoir pipe.

OPERATION

35. Cutting In the Booster.—The passage of the compressed air and the operation of the various valves when cutting the booster into operation is as follows: With the cock in the main-reservoir pipe open, compressed air passes above the outside check-valve *b*, Fig. 10, in the reverse-lever pilot valve. Raising the booster latch *c* depresses the spring cage *d* and results in the inside check-valve being closed and the outside check-valve *b* being opened. The compressed air then passes through the pipe *f* to the preliminary throttle valve, and also through the pipe *g* to the clutch cylinder. The admission of compressed air to the preliminary throttle valve moves its piston down and unseats the steam valve *h*. Steam then passes from the steam-turret pipe to the pipe *i* and thence through the choke *j* to the pipe *k* and to the steam chests of the booster engine, which accordingly begins to turn over slowly. The passage of air to the clutch cylinder moves the piston *l* upwards, and causes the idler-gear rocker to turn on the pin *a* and bring the idler gear into mesh with the gear on the trailing-truck axle. However, there is not yet sufficient steam pressure in the cylinders to cause the booster engine to exert traction on the trailing-truck wheels, and the trailing-truck gear can be regarded at this time as driving the booster engine.

36. The upward movement of the piston in addition to raising the idler-gear rocker, also opens port *m*, Fig. 10, and permits the compressed air to flow through pipe *n* and pipe *p* through the dome pilot valve and through pipe *o* to the throttle operating cylinder. The admission of air to the throttle operating cylinder depresses the piston *r* and opens the main booster throttle *s*. The steam then passes through the steam pipe *k* to the steam chests of the booster engine, which accordingly begins to transmit a turning impulse to the trailing-truck gear and to the trailing-truck wheels.

The cylinder cocks of the booster engine, which up to this time have been open, are now caused to close in the following manner: As soon as the steam pressure in the steam pipe *k*

becomes high enough to compress the piston spring *t*, in the dome pilot valve, the piston in the dome pilot valve lifts, and the inside check-valve *v* seats, and thereby unseats the outside check-valve *q*. This permits the air to pass through the $\frac{1}{32}$-inch drilled hole in the bushing to pipe *w*, the timing reservoir, and thence through the pipes *x* and *y* to the cylinder-cock operating cylinders. The piston *z* moves backwards and draws the operating fingers away from the balls *a′*, which accordingly seat and stop the discharge of steam from the cylinders. The fact that the air passes through a small port in the outside check-valve *q* as well as through the timing reservoir, delays the building up of sufficient pressure to allow the cylinder cocks to close until a certain elapsed period of time.

If desired, the closing of the cylinder cocks can be delayed for any length of time by turning the handle *b′* of the three-way cock vertical. This permits the air that ordinarily would pass to the cylinder cock operating cylinder to pass instead to the atmosphere and the cylinder cocks will not close until the handle is turned back to its original position.

37. Cutting Out the Booster.—The discharge of air from the piping and the action of the various valves when cutting out the booster are as follows: When the booster latch *c*, Fig. 10, drops or is knocked down, the spring cage *d* returns to its normal position, thereby causing the inside check-valve to unseat and the outside check-valve *b* to seat. The air in the pipe *g* and in the clutch cylinder escapes to the atmosphere through the port marked *atmosphere* in the reverse-lever pilot valve, the clutch spring then depresses the idler-gear rocker, and the idler gear is pulled out of contact with the trailing-truck axle gear. With the piston back in its normal position, the air in the pipes *n*, *o*, and *p* exhausts to the atmosphere around the lifting post *c′*, and this causes the spring to move the piston *r* in the throttle operating cylinder back to normal position, thereby closing the main booster throttle. The decrease in steam pressure in the steam pipe *k* when the main booster throttle closes, causes the piston *u* in the dome pilot valve to return to normal position, thereby opening the inside check-

valve *v* and closing the outside check-valve *q*. The air in the cylinder cock piping then passes by the unseated inside check-valve *v* to the atmosphere and the spring in the cylinder-cock operating cylinder moves the piston *z* forwards, thereby opening the cylinder cocks.

38. Idling the Booster.—To idle the booster, thereby warming it up preliminary to cutting it in, the handle of the idling valve is turned to idling position. In this position, the passage from the main reservoir pipe connects to the pipe that leads to the preliminary throttle valve, Fig. 10. Compressed air then opens the preliminary throttle valve, and allows steam from the steam turret to idle the booster.

With the plug cock in idling position, air is admitted through passage *h*, Fig. 18, behind the piston *i*, which moves forwards and prevents the spring cage *a* from being depressed by the booster latch. This indicates that the idling valve handle must be returned to running position before the booster can be cut in.

THE TENDER BOOSTER

39. The tender booster is designed to utilize the adhesion of a pair of the tender-truck wheels, for traction, when the locomotive has no trailing truck. The booster engine, which is of the same type as already described, is mounted on a front tender truck of special design, and is geared to the rear axle of this truck.

As there is not sufficient weight on the wheels of the ordinary tender truck to prevent slipping when the booster is cut in, the equalizers on the forward truck are arranged so that a greater portion of the weight is carried on the rear wheels and less on the front wheels. As an added precaution against slipping, the back truck wheels are connected to the front truck wheels by side rods. Therefore any tendency for the rear wheels to slip will be prevented by the resistance offered by the front wheels.

DISORDERS

40. Air Leaks in Piping.—The air piping should be maintained perfectly tight. Air leaks, if bad enough, will prevent the booster from being cut in; slight leaks will interfere with cutting in the booster properly, but such leaks will assist in the cutting-out of the booster.

41. Gauge Shows Pressure After Cutting Out.—If considerable pressure still shows on the booster gauge after the booster latch has been knocked down, the main booster throttle is partly open or leaking badly. It is not advisable to operate the booster with this disorder, and the turret valves in the steam pipe to the preliminary throttle valve and to the main booster throttle should be closed.

42. Booster Does Not Start.—If the booster does not start when the latch is raised, the turret valves at the main booster throttle valve may be closed, or the preliminary throttle shut-off valve or the valve in the air line may be closed. A bad leak by the packing ring of the piston in the operating cylinder may also prevent the throttle from opening.

43. Gears Do Not Disengage.—If the gears do not disengage when the booster latch is knocked down, with the locomotive in motion, and with little or no pressure on the gauge, either the preliminary throttle valve or the main booster throttle valve is leaking. If in doubt, close the turret valve at both throttles and do not attempt to use the booster until repairs have been made. With the gears engaged, and the booster engine working owing to a leaky throttle, the pressure on the gears is sufficient to hold them in mesh even with no air in the clutch cylinder.

44. Hobnobbing of Gears.—If a continuous hobnobbing of the gears occurs when the locomotive is moving, the spring seat of the clutch cylinder or the spring is probably broken, and the booster should not be cut in until repairs have been made.

45. Booster Idles at High Speed.—If the booster idles at high speed when the locomotive throttle is opened and the

booster latch is down, the trouble is due to the main booster throttle valve not seating properly. The booster should not be used until repairs have been made.

46. Cylinder Cocks Will Not Close.—A failure of the cylinder cocks to close may be due to any of the following reasons: The small hole drilled through the bushing in the dome pilot valve may be closed by dirt or scale, there may be leakage in the air lines to the cylinder-cock operating cylinders, or there may be a bad leak in some part of the control system, some part of the cylinder-cock operating rigging may be binding, or the cylinder-cock cut-out cock may not be closed to the atmosphere.

47. Pistons Stuck.—With the locomotive tied up for some time, as when in the back shop, the pistons of the booster engine are liable to stick in the cylinders, owing to rust, and the booster may be damaged when cut in. A liberal quantity of oil should be introduced into the cylinders whenever there is any likelihood of the booster being out of service for any length of time.

48. Blow at Reverse Lever Pilot Valve.—A blow at the exhaust port of the reverse-lever pilot valve, with the booster cut out is an indication that the outside check-valve is leaking. A blow when the booster is cut in indicates that the inside check-valve leaks.

49. Blow at Dome Pilot Valve.—A blow of air at the dome pilot valve for a brief interval before the booster starts to operate indicates leakage by the outside check-valve. A blow at this port with the booster in operation indicates leakage by the inside check-valve. A leak of steam indicates that the packing ring on the steam piston is leaking or that the piston is not steam-tight on its seat.